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METALLURGY:

THE ART OF EXTRACTING METALS FROM THEIR ORES, AND ADAPTING THEM TO VARIOUS PURPOSES OF MANUFACTURE.

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IRON AND STEEL.

WITH ILLUSTRATIONS, CHIEFLY FROM ORIGINAL DRAWINGS, CAREFULLY LAID DOWN TO SCALE.

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METALLURGY:

THE ART OF EXTRACTING METALS FROM THEIR ORES, AND ADAPTING THEM TO VARIOUS PURPOSES OF MANUFACTURE.

FIRST DIVISION.

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PREFACE.

In the Preface to the First Part of the 'Metallurgy,' which appeared at the end of 1861, it was announced that another volume would complete the Work; and the hope was expressed that it might appear in 1862. But the terms of the announcement have not been complied with, nor has the hope been fulfilled; and an explanation is, therefore, due to the Public. On conferring with many persons engaged in the Smelting of Iron and in the Manufacture of Iron and Steel, the Author became speedily convinced that such a treatise as he had originally intended to prepare on these subjects would not be satisfactory; and he accordingly determined to proceed on a much more comprehensive plan than he had, in the first instance, contemplated. Such a fundamental change has necessitated great additional labour, and a proportionate expenditure of time.

It may probably be thought that the Chemistry of Iron has been somewhat capriciously treated. Thus, while the sulphates of iron are described with much detail, nothing is stated concerning such salts as the chlorides. The fact is, that certain branches of this subject have been considered at greater length than is needed with reference to the Metallurgy of Iron and Steel; but in the Third and concluding Part of this Work the application of what may here seem irrelevant will become manifest.

The results of original investigations will be found scattered through these volumes. It has been objected that in the First Part the details of similar investigations therein might have been conveniently suppressed, and the specific results alone communicated. On the other hand, many persons have expressed their approval of the course which has been followed with regard to original inquiries; and after mature reflection, it has been decided not to deviate from that course.

The chemistry of Iron, notwithstanding all that has been done of late, is yet very imperfect; and some even of the elementary

branches of the subject are extremely obscure. The so-called compounds of iron and carbon, for example, are in this category. The chemistry of Steel is, if possible, involved in still greater obscurity. Problems of the highest chemical interest in connection with the Metallurgy of Iron and Steel await solution. They demand for their successful investigation the exercise of the highest analytical skill, and involve considerations worthy even of study by those who delight in transcendental inquiries. As Reaumur well remarked, "l'utile bien considéré a toujours du curieux, et il est rare que le curieux bien suivi ne mène pas à l'utile."

So much attention has in recent times been devoted to what is usually designated Organic Chemistry, that the field of Inorganic Chemistry has been comparatively deserted, though promising a rich and ripe harvest. In the course of these volumes special points urgently requiring investigation have been indicated.

With regard to cost of production at modern Iron-works, scarcely any information will be found in the following pages. Statements on this subject which have not been derived from actual and *boná-fide* balance-sheets are not trustworthy; and few ironmasters would be willing to have such important commercial details disclosed. Why should they? The Author is in possession of facts as to cost which have been communicated to him in confidence, and which he is not permitted to reveal. Two French metallurgists have recently published the cost of production, etc., at various English Iron-works. They must either have obtained their knowledge from authoritative sources, or have arrived inferentially at their conclusions. The first supposition is not very probable, and figures deduced from personal inspection at a visit cannot inspire us with confidence.

The Author has great pleasure in acknowledging the valuable aid which he has received from the Proprietors and Managers of various Iron-works and others, particularly Mr. Darby, Mr. Adams, and Mr. Parry, of the Ebbw Vale Iron-works; Mr. Clark and Mr. Menelaus, of the Dowlais Iron-works; Mr. Levick, of the Blaina and Cwm Celyn Iron-works; Mr. Octavius Williams, manager of the Morfa Tin-plate Works, Llanelly; Mr. John Kenyon Blackwell, late manager of the Works of the New British Iron Company; Mr. S. H. Blackwell, of Dudley; Mr. C. Arkinstall, manager of the Bromford Iron-works, West Bromwich; Mr.

Henry Marten, of the Parkfield Iron-works, Wolverhampton; Mr. E. F. Sanderson, of Sheffield; Messrs. John Brown and Company, of the Atlas Iron-works, Sheffield, and especially to Mr. J. D. Ellis, of the same works; Mr. George Shaw, of Birmingham; Professor William Pole, of London; Mr. Andreas Grill and Mr. Sandberg, of Sweden; Dr. Hermann Wedding, of Berlin; Professors George J. Brush and J. P. Lesley, of the United States; as well as his former pupils Mr. H. F. and Mr. W. T. Blanford, in India, Mr. H. Bauerman, Mr. W. Weston, and Mr. W. B. Richardson. The special services which these gentlemen have rendered will be found recorded in the text.

But to no one is the Author more indebted than his colleague, Mr. Richard Smith, not only for his experimental and analytical labours, but also for his assistance in the correction of the press. Mr. Smith is the author of the article on the Assaying of Iron Ores.

The labours of Mr. R. W. Mallett, the draughtsman, and Mr. James Cooper, the engraver, of the illustrations in these volumes should not be passed over in silence. It is not possible that greater earnestness should have been displayed in their work, or more conscientiousness in their efforts to attain accuracy of delineation. In the majority of instances the original drawings have been presented to the Author: had it been otherwise, the outlay required for the illustrations, already very considerable, would have been largely augmented, and the price of these volumes greatly enhanced. In nearly every case the woodcuts have been examined by the managers of the works to which they refer, and the descriptions of the processes have also been revised on the spot by the same experienced authorities.

Each Part of this Work will be, as far as practicable, complete in itself, so that a person interested in a special branch of Metallurgy may have the option of procuring the Part devoted to that branch. Yet it need hardly be observed, there is a *vinculum* between the various departments of the Art which renders it impossible to disconnect them perfectly from each other.

The final Part will include the subjects of Lead, Silver, Gold, etc., as specified in the Preface to the First Part.

London, February, 1864.

ERRATA.

Page 17, first line, *for* with *read* into.
„ 104, line 11 from foot, *for* indelibel *read* indelible.
„ 112, line 21 from top, *for* caes *read* case.
„ 137, line 9 from foot, *for* before *read* to be subsequently.
„ 146, line 8 from foot, *for* on *read* in.
„ 158, Table, column 6, *for* commas *substitute* decimal points.
„ 203, line 2 from foot, *for* iron *read* baryta.
„ 379, line 13 from foot, *for* with us *read* as with us.
„ 448, line 17 from top, *for* Redlenbacher *read* Redtenbacher.
„ 493, line 7 from foot, *for* Dale *read* Vale.
„ 523, line 23 from top, *for* on *read* or.
„ 552, line 24 from top, *for* Cumberland *read* Lancashire.
„ 672. The sentence at the bottom of the page, "After the descriptions," etc., should come under the heading "Application of Waste Blast-furnace Gas to Puddling," p. 673.

In one of the Lithographs of the American Anthracite Furnace, the black lines have been put on the wrong side.

Fig. 54, in the gas opening *m*, the black lines should be on the opposite sides.
„ 111, in the oval opening in the casting of the right half of the figure, the black line should be on the opposite sides.

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METALLURGY.

IRON.

PHYSICAL PROPERTIES.

Pure iron in a compact state has been very imperfectly investigated. Certain varieties of *wrought-iron* approach most nearly to the pure metal; but they are all in a sensible degree impure. Whenever the term iron is used without qualification, it is to be understood only to refer either to pure iron or to wrought-iron. In a pulverulent form, as obtained by heating sesquioxide of iron in hydrogen at a comparatively low temperature, it is dull grey, but immediately acquires a metallic lustre under the burnisher. According to Péligot, protochloride of iron is easily reduced when heated in hydrogen, and the metal thus procured is filamentous, compact, malleable, and almost as white as silver.[1] Berzelius recommends the following process for the preparation of *perfectly pure* iron from the wrought-iron of commerce:—Iron filings, in admixture with $\frac{1}{4}$ of their weight of sesquioxide of iron, are to be heated under pounded glass free from metallic impurities, in a covered and luted Hessian crucible, during an hour, in a smith's fire, with coke as the fuel. Thus made, iron is described as approximating in whiteness to silver, as extremely tenacious, softer than ordinary bar-iron, and in fracture scaly, conchoidal, and occasionally crystalline.[2] I have tried this process, and obtained somewhat different results. Very fine wire was cut into small pieces and treated in the manner above described, under plate-glass. A well-melted button was found at the bottom of the crucible. It was nicked across the middle, and then broken. The fracture was largely crystalline, and greyish-white in colour; the metal was comparatively soft and malleable; a portion of it was first hammered, and then rolled out cold into thin strip; but the edges were jagged: the specific gravity before rolling was 7·8707, and afterwards 7·865; this iron was certainly not pure, as it dissolved easily in hydrochloric, or dilute sulphuric acid, with the evolution of fetid hydrogen. Broling had previously obtained similar results with respect to specific gravity: thus, he found that of melted bar-iron to be 7·8439, whereas in the same iron in very thin sheet it was reduced to 7·6, and to 7·75, in square wire a little less than 2^{mm} (0·08 in.) in diameter.[3] Berzelius remarks, "that it might seem that these anomalies proceeded from repulsion between the surface

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[1] Rapp. Ann. Par Berzelius. Trad. par Plantamour. 5ième année. 1845, p. 76.

[2] Berzelius, Tr. 2, p. 655.

[3] Ibid. p. 656.

of the iron and water, as the specific gravity decreased in proportion to the extension of the surface of the metal. The surface, however, had been freed by means of caustic potash from all foreign matters which might prevent adhesion between the metal and water." Hence he refers the phenomenon to the mechanical treatment of the metal after fusion. The specific gravity of copper, it will be remembered, is also changed in a similar manner by such treatment. The only pure iron in a compact state which I have seen is that deposited from solution by electrolysis. I received from the late Mr. Henry Bradbury thin laminæ of iron, which he obtained in the process termed *aciérage*, or that of protecting engraved copper-plates with a coating of electro-deposited iron, in order to enable them better to resist the wear of the printing-press. The solution employed contained protochloride of iron and chloride of ammonium.[4] The metal is thrown down as a thin, bright, and firmly-adherent layer; and, with proper treatment, its deposition may be so exactly limited to the surface of the copper, without affecting the engraved lines, that an impression of a plate after aciérage cannot be distinguished from another previously obtained from the same plate. The bright polish of the deposited iron is remarkable; and hitherto it has not been found possible to increase the thickness of the coating beyond a mere film and retain this polish. A solution of iron containing cyanide of potassium is employed in the process. I have made numerous experiments upon this iron, which will be duly recorded hereafter. It is scarcely acted upon at the ordinary temperature, either by hydrochloric or sulphuric acid; but, on the application of gentle heat, it dissolves with the evolution of hydrogen, which is perfectly free from the least trace of the peculiar fetid odour of the gas produced from every kind of wrought-iron. Barruel states that he has kept electro-deposited iron during many years in a cupboard, in which acid vapours were constantly present, and yet it presented not the faintest trace of rust.[5] According to my experience, such iron rapidly rusts when exposed to the joint action of air and moisture. Mr. Matthiessen informs me he has reason to infer that electro-deposited iron possesses much higher electric conductivity than any specimen of commercial iron which he has examined. It is susceptible of a high polish, and the colour of the bright surface, to my eye, is greyish-white. Its specific gravity is 8·1393. As the specimens in my possession were small and extremely thin, very great care was required in determining the specific gravity. Six determinations were made by Mr. Smith with different pieces, and that given above is the most trustworthy. In the other five results the extremes were 7·9405 and 8·107. The piece which gave the number 8·1393 was $1\frac{1}{4}$ in. long and $\frac{3}{4}$ in. wide. In air it weighed 6·772 grains, and in water 5·940. It was boiled in water during $1\frac{1}{2}$ hour, left to cool therein, and weighed exactly at 15·5° C.

[4] Vide Specification, A.D. 1858, No. 667. In the name of E. A. Jacquin, being a communication from M. Garnier of Paris.

[5] Traité de Chimie Technique, etc. Paris. 1857, 3. p. 21.

or 60° F. Its malleability is not affected by rapid cooling after exposure to a high temperature. Strips of this electro-deposited iron were plunged, while red-hot, into mercury, without becoming in the slightest degree hardened or less easily flexible; but I do not remember to have seen any specimen of commercial iron, even in the thinnest sheet, that was not rendered sensibly harder and more rigid by this treatment.

The iron is deposited from a solution of a salt of protoxide, such as protochloride or sulphate; and the presence of chloride of ammonium is stated to be essential to produce a smooth, polished, steel-like surface. With a very strong current, or a very small pole, much hydrogen escapes, and the precipitated metal, when of a certain thickness, appears porous and spongy. If this is washed and dried over caustic potash, it smells strongly of ammonia, and continues to do so for a long time; by heating to redness, the odour of ammonia becomes stronger, and then ceases; by boiling the powdered precipitate in water, hydrogen is copiously evolved. Meidinger is of opinion that the precipitated iron is combined with a very small quantity of nitrogen, producing a steel-like alloy; and in the analysis of a specimen smelling strongly of ammonia he found at the most 1·5% of ammonium. Krämer announces that in a similar precipitate he found 1·49% of nitrogen, and that iron thus electro-deposited resembles in its physical characters iron-wire which has been exposed at a red-heat to a current of ammonia.[6] These statements may be correct, but they need confirmation.

Crystalline system.—Iron crystallizes in the cubical system. Wöhler has described artificially-formed cubes and octahedrons of iron. The former were readily obtained on breaking cast-iron plates, which had been long exposed to a white-heat in the brick-work of an iron-smelting furnace; and the latter were found lining cavities in a large unsound cast-iron roll.[7] Augustin observed distinct cubes on the fractured surface of gun-barrels which had been long in use.[8] I have large and pretty distinctly formed solid as well as skeleton octahedrons in cast-iron. I am indebted to Mr. Faraday for a small piece of nearly round rolled bar-iron which had been exposed for a considerable time in a pot of melted glass, and which is highly crystalline, presenting even on its surface large, prominent, and distinct markings, apparently of skeleton octahedra. I am also indebted to Mr. Sopwith for another piece of flat bar-iron, which had long remained in a pot of melted glass. The fracture is highly crystalline and bright. There is a distinct line or fissure extending longitudinally across the fracture, but not quite in the centre. The cleavage planes are arranged perpendicularly to the external surface. The external surface of the bar is for the most part coated with black scale; and where it is not so coated, the metal is bright and approximating to silver in whiteness; superficially it is not in the least crystalline like the former specimen, though covered with

[6] L. u. K. Jahresb. 1861, pp. 304, 305.

[7] Berzelius, Jahresb. 13. p. 116.

[8] L. u. K. Jahresb. 1847, p. 281.

fine hexagonal markings, suggesting a columnar structure. I have seen specimens of iron produced by Mr. Bessemer's process, which are intensely crystalline in fracture. Professor Miller, of Cambridge, informs me that he has found the Bessemer iron to consist of an aggregation of small cubes. "The crystals," he remarks, "are very imperfect, as might be expected, in consequence of their not having room to develope their faces; yet I think there can be no doubt of their form, some of them being measurable and giving angles of approximately 90°. The system to which they belong is, of course, the cubic." I have reason to believe that the crystals examined by Professor Miller were quite free from carbon. It may, however, be objected that the preceding observations relate only to impure iron; but, in reply, it may be stated that the proportion of foreign matter in comparison with the iron was very small, and that there is not, I believe, any instance known of an alteration in the crystalline system of a metal due to the presence of a comparatively small amount of foreign matter.

Poumarède states that protochloride of iron, with the aid of carbon, is reduced by the vapour of zinc, and that the iron set free is in a dendritic form, frequently in hollow tetrahedrons, of the specific gravity 7·84.[9]

Fuchs has put forth the notion that iron is dimorphous, crystallizing in the cubical and rhombohedral systems; but the arguments by which he supports this view are unsatisfactory. He considers it proved that malleable iron belongs to the cubical system. On this point there can be little doubt, though Fuchs cannot infer it analogically from the fact, that "all other malleable metals possess crystalline forms belonging to this system." Now, zinc must surely be regarded as a malleable metal, and it is rhombohedral. On the other hand, the metallic compound of titanium formed on the hearths of iron smelting furnaces is brittle, yet cubical. Cast-iron is supposed by Fuchs to belong to the rhombohedral system, and steel to consist of an alloy of cubical and rhombohedral crystals, of which the proportions vary according to the "temper," the rhombohedral crystals preponderating in hardened steel, and the cubical crystals increasing in the ratio of the softness of the metal. "The two kinds of iron in steel may be regarded as in a state of constant mutual tension, which may perhaps be the reason why steel retains permanently communicated magnetism, while malleable iron does not."[1]

Magnetism.—Iron is strongly attracted by the magnet, but when pure it speedily loses any magnetic power which it may have acquired by induction. Matteucci found that a drop of iron melted by the oxy-hydrogen blow-pipe was still taken up by an electro-magnet.[2]

Tenacity.—I am not aware whether the tenacity of *pure* iron has been determined. The iron of commerce varies considerably in tenacity, according to the nature and amount of foreign matters in it, its internal

[9] L. u. K. Jahresb. 1847, p. 281.
[1] Chemical Gazette, 1853, 11. p. 94.
[2] L. u. K. Jahresb. 1853, p. 255.

structure, the diameter of the pieces operated on, the temperature, etc. *Tensile strength* is the expression usually employed by engineers to designate tenacity; and, for the sake of comparison, it is always computed for one square inch of transverse sectional area. This subject is of the highest practical importance with reference to the art of construction; but the discussion of it will be more appropriate at the end of the volume than in this place, after we shall have passed in review the different processes of manufacturing iron and considered the foreign ingredients which occur in different kinds of commercial iron. According to Dufour the tenacity of iron is increased by the passage through it of an electric current. Thus an iron wire 0^{m} 009248 in diameter which sustained only 2545 kil. held 2898 kil. after the action of a current of a Bunsen cell during 463 hours.[3]

Specific heat.—According to Regnault it is 0·113795.[4] This determination was made with iron wire 0^{m} 003 in diameter, which was extremely soft and yielded no sensible residue when dissolved in hydrochloric acid. The same wire heated to whiteness, plunged into water, and afterwards cleaned with hydrochloric acid, was also operated on and with substantially the same numerical result. In five determinations the extremes were 0·11284 and 0·11398.

Dilatation by heat.[5]—

	Nature of Iron.	Name of observer.	Coefficient.
Linear	Soft iron forged	Lavoisier and Laplace	0·000012204
	Iron drawn round	,, ,,	0·000012350
	Iron	Smeaton	0·000012583
	Melted wrought iron	Roy	0·000011100
	Drawn iron wire	Troughton	0·000014401
Cubical		Kopp	0·000037[6]

Action of heat. Welding.—Iron requires a very high temperature for its fusion. Its melting point has not yet been determined with certainty, but has been estimated at 1550° C. by Pouillet, which, however, is questionable. We have no difficulty in fusing it perfectly in our assay-furnaces in which platinum remains infusible. Iron has one remarkable and very important property, namely, that of continuing soft and more or less pasty through a considerable range of temperature below its melting point. It is sufficiently soft at a bright red-heat to admit of being forged with facility, as every one knows; and, at about a white-heat, it is so pasty that when two pieces at this temperature are pressed together they unite intimately and firmly. This is what occurs in the common process of *welding*. Generally metals seem to pass *quickly* from the solid to the liquid state, and so far from being pasty and cohesive at the temperature of incipient fusion, they are extremely brittle and in some cases easily pulverizable. But, admitting that there is a particular temperature at which a metal becomes pasty, its range is so limited in the case of the common metals, that it would scarcely be possible to hit upon it with any certainty in practice;

[3] L. u. K. Jahresb. 1855, p. 65.

[4] Ann. de Chim. et de Phys. 1840, 73. p. 37.

[5] Jamin, Cours de Physique, 1859, 2, pp. 374-382.

[6] L. u. K. Jahresb. 1851, p. 55.

or, if it were possible, its duration would be too short for the performance of the necessary manipulations in welding. Besides, there is another condition which might interfere with the process. In order that union should take place between two contiguous surfaces of a metal, it is obviously essential that they should not be covered with any infusible matter, such as scale due to oxidation. In heating iron to the welding temperature, a scale is formed, which may be immediately converted into very fusible and liquid silicate of protoxide by throwing a little sand over it, when welding may be effected, the silicate being squeezed out during the operation and clean metallic surfaces brought together. Every blacksmith resorts to this simple expedient of using sand as a flux. But in the case of some of the common metals, it would not be very easy, or indeed practicable, to find a suitable flux and to insure this condition.

It is maintained that iron completely free from carbon, or nearly so, can hardly be welded, or not without great difficulty, and then only imperfectly.[7] The so-called "burnt iron," with which every one practically acquainted with forging is familiar, is adduced in illustration. While we reserve for future consideration the nature of this well-known variety of iron, let us admit, for the sake of argument, that its alleged peculiarity in this respect depends upon the cause assigned, and inquire how far this cause is compatible with the theory which has been advanced in reference to the unweldableness of such iron. According to this theory, if I understand it correctly as propounded by Scheerer, the carbon acts by instantly reducing any thin layer or skin of unmelted oxide of iron which may exist on the surface of contact of two pieces of iron brought together at a white-heat, and which if persistent would obviously tend to prevent their welding with each other. Now, any one who has attentively watched the operation of welding will, I think, find it difficult to accept this explanation. The two pieces of iron at the moment of contact are invariably coated with a comparatively thick layer of scale, though they may have been heated in the midst of incandescent carbonaceous matter and brought very quickly together. A piece of iron at a welding heat cannot be exposed to the atmosphere for an instant without acquiring such a coat; so that supposing it to have a clean metallic surface while in the fire, there would be ample time for superficial oxidation during its removal to the anvil. The scale upon iron at a welding heat is either liquid or solid. If liquid, we know that welding may be effected with the extrusion of the melted scale, and there is no necessity for the alleged reducing action of carbon in the iron; but if the scale be not liquid, we know that welding cannot be effected, though carbon may be present in the iron.

The so-called "burnt iron" is largely crystalline for reasons which will be stated in the sequel, and cannot be forged without special precautions. It is not proved that this depends on the absence of carbon, and it may be due to peculiarity of internal structure. Indeed "burnt

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[7] Scheerer, Lehrb. d. Metall. 1. p. 553.

iron," which presents on fracture a flaky crystalline appearance, similar to that of some kinds of galena, may with proper care be hammered into a bar which shall exhibit a thoroughly fibrous fracture. But such iron cannot be forged under precisely the same conditions as common bar iron, and what cannot be forged cannot be soundly welded; but an ordinary smith would pronounce iron which needs unusual precautions under the hammer to be unforgeable and unweldable. Hence, the non-capability of welding, which is due to peculiarity of internal structure, may have been erroneously attributed to deficiency or entire absence of carbon.

The following experiments by Mr. Riley, at the Dowlais Iron-works, will show that largely crystalline iron may be welded. The kind of sheet iron known as "black plate" from tin-plate-works was cut in pieces $\frac{3}{8}$ in. square, and melted in a crucible under slag produced in assaying iron ore. A well melted, smooth, even button of iron, weighing 1638 grains, was obtained under a layer of dark green cinder. On attempting to cut the button with a "cold" chisel, the former broke with a very crystalline fracture in the direction of the cleavage planes of the crystals. Half of the button was worked out by a smith into a bar $\frac{1}{4}$ in. square. The iron was very soft, and had a fine face and sharp even edges like steel; two pieces were welded together: whilst at a welding heat the iron worked very well; on cooling to a red heat it became cracky and broke; the fracture of the iron not exposed to a welding heat was very silky, and it was readily bent double without cracking, the smith stating it was some of the toughest iron he had ever worked. Other experiments of a similar kind were made by Mr. Riley, who deduced from them the conclusion: "The property of becoming useless after exposure to a welding heat appears from the above experiments to be a special character of fused wrought iron. The experiments have not been carried far enough to lead to any explanation of this: it may probably be due to the absence of a small quantity of carbon usually present in wrought iron. In Bessemer's iron [Mr. Riley believes], there is no carbon, yet it certainly welds, though not very well."

At present we know nothing of the working qualities of absolutely pure iron, and there is certainly no evidence to prove that it will not weld. On the contrary, both *à priori* reasoning and the facts advanced seem to justify the opposite conclusion. It may be that the presence of a *very minute* proportion of carbon greatly improves the working qualities of iron; and we have seen how strikingly the malleability of copper is affected by the presence of very small quantities of certain kinds of foreign matter. If, however, it should hereafter be clearly demonstrated that the welding quality of iron is promoted by the presence of a little carbon, the mode of action which Scheerer ascribes to this element in the operation cannot be accepted without adequate proof.

It should be here stated that platinum, which is considered a weldable metal, and is usually classed with iron in that respect, seems to pass very rapidly from the solid to the liquid state; and in the

operation of melting of several hundred ounces of platinum by oxygen and coal-gas at Messrs. Johnson and Matthey's, which I had the pleasure of witnessing, I was struck with the great liquidity of the metal instantly after fusion. Copper in a fine state of division, as when precipitated, will cohere and form a solid mass under great pressure; and copper medals have been struck by Ozann on this principle. Gold and silver in the state of fine powder may be converted into a compact metallic mass in the same way. The powder of silver produced by decomposing chloride of silver with zinc, etc., is gently heated, then compressed, hammered, and reheated alternately, the temperature always being sensibly below the melting point of silver. Fournet obtained bars by this means which might be wrought like bars resulting from fusion. He also made damaskeened bars by using gold and silver powder in alternate layers. Fournet regards this as true welding, *i.e.* union at a temperature below fusion; and he considers that the firm union effected between two freshly cut surfaces of lead by simply pressing them together is welding.[8] It may, indeed, be only a question of degree, and the conversion of a metallic powder like spongy platinum in the usual manner by frequent compression and subsequent heating below the melting point into a compact metallic mass should be regarded as analogous to the welding of iron.

Iron may be volatilized at extremely high temperatures, such as may be attained by voltaic electricity and the combustion of the metal in oxygen.

Crystalline and Fibrous Iron.

After fusion, iron is highly crystalline; and even a small button, weighing only an ounce or two, may present on fracture large bright cleavage planes, and its surface will always exhibit distinct crystalline markings when slowly acted upon by dilute hydrochloric or sulphuric acids. This etching action is not, as some might suppose, due to the interposition of foreign matter symmetrically diffused through the mass. Many examples of the apparent development of structure by the action of solvents might be mentioned. The crystalline structure in all such cases pre-exists, and is merely rendered manifest by this etching process. Different faces of the same crystal are found to be attacked in different degrees by the same solvent; and Professor H. Rose informed me long ago that an excellent illustration of this fact was presented by a crystal of quartz when exposed to hydrofluoric acid. Similar faces were acted upon with equal intensity. But what is true of quartz, which is rhombohedral, would not necessarily be true of iron, which is cubical, unless the crystals of the latter presented original and derived faces, as in the cubo-octahedron. The crystallization of iron has excited much attention, especially amongst engineers; and, although much has been talked and written about it, yet no small confusion respecting it still prevails. However, a careful

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[8] Sur la soudabilité des métaux et sur le damassé d'or et d'argent. Par M. Fournet. Ann. de Chim. et de Phys. 1840, 74. p. 435.

examination of the subject will tend to remove this obscurity. Bar-iron acquires a largely crystalline structure by long exposure to a temperature which, though high, is yet very far below the melting point of the metal. On the application of a certain amount of heat, the particles have sufficient freedom of motion to arrange themselves in crystals. We have previously had a striking illustration of this fact in the annealing of sheet-zinc at a temperature bordering on, yet sensibly below, its melting point.[9] Hence we can readily understand why iron which has been frequently and strongly heated, or iron which has been forged into large masses, and which must necessarily have been subjected during a considerable time to a high temperature, should tend to become largely crystalline in structure. The operation of hammering iron while strongly heated and during cooling to a certain degree will obviously interfere with the action of the forces which determine crystalline arrangement, and may, consequently, be expected to diminish the size of the crystals. But in the case of large masses, it will be difficult to affect the metal far below the surface, unless a very heavy hammer is employed and very powerful blows are applied; and even then it is hardly possible to conceive that uniformity in the size of the crystals should be produced through the mass. For, when the exterior may be cooled down to redness, the interior must still be at a much higher temperature, it may be white hot; so that on subsequent cooling, after the cessation of the blows, the particles in one part of the mass will be in a condition to assume a more largely crystalline structure than those in another part. It is this which constitutes the difficulty in large forgings; and it cannot be overcome by continuing the hammering until the metal in the interior is sufficiently reduced in temperature to prevent the formation of large crystals in that part; for, if the metal on the exterior were hammered at too low a temperature, as would certainly be the case in the condition supposed, it would become brittle and tender. It must be borne in mind that these remarks relate to iron, and not to steel or iron containing any sensible proportion of carbon. With reference to the size of the crystals, it should here be stated that the presence of phosphorus favours the formation of large crystals; and this element occurs in most commercial varieties of British iron. The rapid cooling of large forgings by immersion in water might be expected to render the interior less largely crystalline.

When iron is hammered cold, especially in various directions, the crystals of which it consists will obviously become more or less disag-

[9] It has been previously shown that a largely crystalline ingot of this metal may, under certain special conditions of temperature, be reduced to thin sheet, which is flexible to a considerable extent without rupture, and which, on bending backwards and forwards, emits no crackling sound like tin when similarly treated. But this sheet, by exposure to a temperature sensibly below the melting point of zinc, is rendered very brittle, emits a crackling sound on bending, and breaks with a comparatively largely crystalline fracture. Sufficient freedom of motion must, therefore, have been given to the particles, even while the metal was still *solid*, to enable the crystalline forces to act and reproduce a largely crystalline structure.

gregated, and, therefore, the strength of the metal will be diminished. The larger the crystals, the more easily will the iron break; for, as fracture will occur in the direction of least resistance, which is that of the cleavage planes, and of the planes of junction of contiguous crystals, it will be facilitated in proportion to the size of these planes. I have buttons of fused iron, in which the crystals are so large that the cleavage planes extend completely across the fracture. On the other hand, when the crystals are comparatively small, they are, so to speak, more interwoven with each other, there are no large cleavage planes, and, consequently, there is less tendency to fracture. Whether the foregoing considerations be correct or not, it is well established in practice that largeness of crystal in a bar of iron indicates facility of fracture. In illustration of the effect of cold hammering upon iron, I give the following result of experiments which my friend Mr. S. H. Blackwell, of Dudley, made at my request:—A solid cylinder of iron, being part of an axle, 18 in. long and 3½ in. in diameter, was hammered cold by subjecting it first to about twenty blows on the side under a helve of 3 tons, and then upending it and continuing to strike it on end 80 or 90 times; it was afterwards hammered under a larger helve of about 4½ tons, and broke after 10 or 12 blows from a height of 3 ft. The fracture was crystalline; but a piece forged out of another part of the same axle exhibited a fibrous fracture on bending it over a sharp curve by hydraulic pressure amounting to 12 tons.

When a piece of iron which has been melted, and which is largely crystalline, is cautiously hammered at a suitable temperature into a shape adapted for rolling, and then rolled into a bar not too thick, it will present either a fibrous or a crystalline fracture according to the manner of breaking it, and, especially, the duration of the act. After nicking it to a slight depth on one side with a cold chisel, and then bending it slowly backwards from the line of the nick, the fracture will be highly fibrous, and may be almost silky. On the other hand, if it be nicked all round, and afterwards suddenly broken in the line of the nick, the fracture will be crystalline, with, it may be, only here and there an indication of fibre. By the operation of rolling, the crystals are drawn out *in one direction*, into wires, as it were; and the resulting bar, therefore, will be composed of parallel and continuous bundles of such wires. But the crystalline structure is not thereby obliterated, the crystals having been merely elongated; and, accordingly, every bar, even down to the smallest size, should on sudden transverse rupture present a crystalline fracture, the appearance of which will become indistinct in proportion to the extension of the crystals, or, in other words, to the degree of rolling. In the process of wire-drawing, the same result should occur; and the fracture, even of the finest wire, when suddenly effected, should be crystalline, though it may be very minutely so. Time plays a most important part in determining the character of the fracture. When the metal is broken with extreme rapidity, there is no time allowed for the exercise of the property of ductility, and the fracture will necessarily be crystalline; but, on the contrary, when rupture is slowly produced, there is ample time for

the exercise of that property, and during the act of bending a bar in order to break it, the crystals on the convex side in the place of flexure actually undergo a process equivalent to wire-drawing, and so tend to develop fibre on fracture. However, in every rolled bar, it has been shown that fibres in the form of elongated crystals pre-exist. Hence the fibrous fracture of a bar of rolled iron is partly the result of the operation of bending, and partly of that of rolling. In a rolled bar of iron the fibrous structure may be rendered manifest by the etching action of acids, as is the crystalline in a piece of iron which has been melted, and for precisely the same reason. In an ordinary rolled bar of iron there is, as will hereafter be explained, another cause inducing the manifestation of fibre by this etching action. There is always some silicate of protoxide of iron remaining in such a bar, and this becomes extended along with the iron during rolling; as acids do not act upon this silicate and the metallic iron with equal intensity, it is clear that their solvent action will cause the appearance of fibre. This silicate is apt to be irregularly diffused, and to occasion corresponding irregularity in the etching process, deep furrows and holes having been frequently the result.

Practical demonstrations of the correctness of the preceding views concerning the influence of time on the character of fracture have been obtained at Shoeburyness, in experiments to determine the quality of iron best adapted for armour-plates. What is known as good fibrous iron has presented a crystalline fracture under the impact of shot, varying in velocity from 1200 to 1600 ft. in a second. Moreover, in some cases, the portion of the plate struck has been shattered to fragments, as though it had been glass.

The question will naturally suggest itself, whether gentle vibration, the result of very frequently repeated light blows, or of vibration without impact, caused by jarring-grinding action, as in an axle working on badly lubricated bearings, or of straining and torsion in shafts, etc., very much less intense than would be produced by heavy hammering, would tend to induce permanent disaggregation of the crystals of iron and consequent tenderness. It is a question of great practical importance in reference to the use of iron, as in chains in coal-pits, and on railways, where the safety of human life is concerned. Opinions are divided upon it, and I am not acquainted with any precise experimental *data* to justify any very positive conclusion on the subject. Many instances are recorded in which vibration is alleged to have induced permanent brittleness; but, if I be not mistaken, the iron reported to have thus deteriorated in strength has not, at least in many cases, been properly examined and tested. Changes in mechanical properties of the metal may have been attributed to vibration, which were in reality due to original and undetected flaws. In certain metallic alloys it is well established that vibration may cause great alteration in structure, and, as a consequence, extraordinary brittleness; and in the former volume, in the article on Brass, decided instances of such alteration are recorded. But it may be objected that alloys are one thing, and a simple metal another and very different thing; and that, although

the former may be affected by gentle and sufficiently-repeated vibration, it by no means follows that this should be the case with the latter. Accurate experiments will alone determine the force of this objection; nevertheless, it seems reasonable to suppose that a simple metal, like iron, should be affected by exposure to the conditions in question. The expression, gentle vibrations, is after all indefinite, and may include very different degrees of concussive action; and much may depend on a comparatively slight difference in the intensity of such action, especially when occurring at different temperatures comprised even within the comparatively narrow limits of ordinary atmospheric variation. The frequent accidents which occurred from the breakage of iron on railways a short time ago during the prevalence of a severe frost are confirmatory of this opinion. Moreover, it has been clearly demonstrated that the tenacity of iron varies considerably at temperatures not far remote from each other. It is most desirable that this subject should be accurately investigated; and the Institution of Civil Engineers would render excellent service by conducting an elaborate experimental inquiry concerning it.

Another point remains to be considered—namely, whether vibration caused by impact, or otherwise, may induce a crystalline arrangement which did not previously exist, or was only imperfectly developed. I have not met with any evidence to justify an answer in the affirmative. All iron after fusion, or after having been exposed to high temperatures sufficient to induce softening and pastiness, consists, as we have seen, of an aggregation of crystals. In the act of rolling or extension of any kind, these crystals are elongated, but not obliterated; and they may always be rendered manifest by sudden fracture. Now, when a bar becomes brittle by hammering cold, there is no reason to suppose that this result is due to the actual development of a crystalline structure; for the loosening or disaggregation of the crystals originally composing the mass appears quite adequate to account for the brittleness. If such a bar had, previously to hammering, been broken under special conditions so as to allow time for the exercise of the property of ductility, it would have presented a fibrous and not a crystalline fracture.

Neglect in observing the essential connexion between the character of the fracture and the particular mode in which it has been effected has led to the conclusion, that the crystallization of iron has originated from mechanical treatment, when, in reality, crystalline structure pre-existed, and was only rendered easily manifest by fracture consequent on induced brittleness.

An excellent digest of information published on this subject is contained in Mr. David Kirkaldy's recent valuable work on the Tenacity, or, as it is now termed, *Tensile Strength* of Iron and Steel;[1] and the author appears to have arrived at nearly the same conclusions

[1] Results of an Experimental Inquiry into the comparative Tensile Strength and other properties of various kinds of Wrought Iron and Steel. 8vo. London, 1862.

as myself. I may be permitted to state that, during many years, I have annually communicated to the metallurgical students at the Royal School of Mines the statements and deductions therefrom which I have here expressed. A few observations on the production of crystalline and fibrous fracture have already appeared in the former volume.[2]

CHEMICAL PROPERTIES OF IRON.

Atomic weight. 28. (Svanberg.)

IRON AND OXYGEN.

In perfectly dry oxygen, iron in a *compact* state undergoes no change at the ordinary temperature of the atmosphere; but when in a state of very fine division, like that obtained by reducing sesquioxide of iron by hydrogen at a very low temperature, it takes fire when gently heated in atmospheric air, and is converted into sesquioxide. Iron thus finely divided is stated to be pyrophoric when quite cold. Mr. Dick has made some experiments on this subject in my laboratory. Pure sesquioxide of iron was prepared by the addition of ammonia in excess to a solution of sesquichloride of iron and perfectly washing the precipitate thus formed. Reduction was effected in a glass tube by hydrogen which had passed through sulphuric acid, and then over chloride of calcium and fragments of potash. The oxide was finely powdered, and gentle heat applied by means of a spirit-lamp. The reduced metal ignited when shaken into the air out of the tube, but only so long as the latter continued sensibly warm to the hand. After it had become quite cold in the atmosphere of hydrogen, it was ignited by gently warming it on a sheet of paper far below 100° C., the product of the combustion being sesquioxide. The iron obtained in some experiments could only be ignited at somewhat above 100°. It appeared that in every case after perfect cooling the iron required a higher temperature for ignition than previously, but this, it should be stated, was not confirmed by thermometrical observations. In no experiment was iron obtained which was pyrophoric after having become quite cold. When dropped into hot air, it burned brilliantly. We owe to Magnus the following interesting observations on this subject. Reduction of sesquioxide of iron in hydrogen begins at the boiling-point of mercury, and is completed between this and the melting-point of zinc; and when the temperature at which reduction is effected does not exceed the last-named limit, the product is pyrophoric, but ceases to be so if heated beyond this limit.[3] On displacing the hydrogen, after reduction of the oxide, by a current of carbonic acid, and allowing the iron to cool in this gas, the pyrophoric property was destroyed. Hence it was inferred that this property depended upon the condensation of hydrogen in the reduced iron, which spontaneously ignited in contact with atmospheric air. The remarkable property of certain pulverulent

[2] Metallurgy, First Part, p. 7.

[3] Berzelius, Jahresb. 7. p. 142. Vid. also 6. p. 155 of the same work for the subsequent information on Magnus's experiments.

matters, such as platinum-black, in determining the combustion of gases and vapours in contact with air, is now well known. The correctness of the preceding inference was not confirmed by the experiment of heating oxalate of iron at the lowest temperature at which decomposition occurs, and allowing the residue to cool in the gases evolved, which consist chiefly of carbonic acid. There was no hydrogen, and yet the product was pyrophoric. It will be seen further on that this product is a mixture of protoxide of iron and metallic iron. When sesquioxide of iron is precipitated in conjunction with about 3 per cent. of alumina or silica so as to be intimately mixed throughout, it may be reduced at a red heat in hydrogen and yet be pyrophoric, the infusible and interposed foreign matter tending to prevent the particles of iron from sintering together, and to keep them in a state of fine division.

Mr. Dick endeavoured to ascertain whether iron reduced by, and cooled in, hydrogen retained any portion of this gas; but the results were not very conclusive. Spongy platinum and platinum-black were intimately mixed with the iron, without yielding decided evidence of the formation of water. Some of the iron was placed on a little chlorate of potash, previously melted and afterwards solidified at the bottom of a test-tube; heat was applied, ignition occurred, but there was no appearance of the condensation of water on the cold part of the tube.

Iron in a compact state, heated to redness in oxygen, burns with vivid incandescence, forming an oxide which drops in well melted globules, and of which the composition, according to Marchand, is represented by the formula Fe^4O. Every one is familiar with the beautiful experiment of plunging a thin iron wire with the end red hot into this gas. Iron also burns vividly at a white heat, or somewhat below, in atmospheric air. In the puddling furnace, to be hereafter described, this phenomenon may be daily witnessed. Nail-makers, or, as they are termed, nailers, in some localities avail themselves of the combustibility of iron at high temperatures to keep their nails hot during the process of forging. There is a little blowpipe connected by a tube with a small pair of double bellows fixed above, and by this means a jet of air is thrown on the iron when it is becoming too cold, and immediately the temperature is much increased. I have seen this simple and really beautiful expedient in operation at Ruabon, North Wales, though I do not remember observing it amongst the nailers in the vicinity of Birmingham, whom I have often watched at their work. Yet the late Mr. Richard Phillips published the fact of his having seen it in this locality.[4] If a rod of iron be tied to a piece of cord at one end, heated to whiteness at the other, and then swung round rapidly, a brilliant circle of sparks will be produced by the combustion of the metal, resembling a fire-work.[5] Iron in a compact state readily oxidizes at a dull red heat in atmospheric air; and the nature of the oxide produced varies considerably if the temperature be raised to bright redness or whiteness.

[4] Phil. Mag. ii. p. 407. 1837.

[5] D'Arcet. Berzelius, Jahresb. 15. p. 160.

It has been stated by some persons that iron has the property of dissolving oxygen, or rather oxide of iron, in small quantity, just as copper dissolves its dioxide; but, so far as I am aware, no satisfactory evidence has ever been advanced in support of this statement. One experiment on this point has been made in my laboratory by Mr. Dick, but the result is inconclusive. I publish it merely to excite attention to the subject. About 450 grains of pure sesquioxide of iron were mixed with as much lampblack, prepared in the laboratory from re-distilled oil of turpentine, as sufficed to reduce 370 grains of the oxide to the metallic state, thus leaving a considerable amount of unreduced oxide. The mixture was intensely heated in a French clay crucible, when a well-melted button of iron was obtained, covered with a layer of well-melted slag. The iron was very soft, and clogged the file. Filings to the weight of 150 grains were placed in a combustion-tube of hard glass, at one end of which a current of well-dried hydrogen was admitted, passing out at the opposite end through a weighed chloride of calcium tube. After filling the combustion-tube thoroughly with hydrogen, the part of the tube containing the iron was heated to redness, and kept at that temperature during about half an hour, hydrogen slowly circulating through all the while. The chloride of calcium tube increased 0·235 grain in weight, which would indicate the presence of 0·0174°/。 of oxygen, or 0·0609°/。 of protoxide of iron, in the filings. This single result, I repeat, cannot be accepted, and may possibly be proved erroneous.

Protoxide of iron. FeO.—It is generally asserted that this oxide is unknown in a separate state; but, according to Debray, it is produced when hydrogen and steam, in certain proportions, are passed over heated sesquioxide of iron.[6] Thus prepared, it is described as black, non-magnetic, and easily burning in atmospheric air, with the formation of magnetic oxide. When dry oxalate of protoxide of iron is heated without access of atmospheric air, the residue, according to Liebig, is protoxide of iron containing some metallic iron, and the volume of carbonic oxide evolved is consequently less than that of the carbonic acid. It ignites spontaneously in the air, and is converted into sesquioxide of iron.[7] Protoxide of iron is a powerful base, and in combination frequently occurs in metallurgical operations connected with iron. It is precipitated by potash or soda from aqueous solutions of salts of protoxide of iron, in the state of a flocculent white hydrate, which, in contact with air, immediately absorbs oxygen and becomes green, owing to the formation of some magnetic oxide. It is certainly soluble, to a slight extent, in fused potash. I was accustomed to prepare pure potash by the alcohol process, and in the first evaporation of the aqueous solution I employed a cast-iron vessel, when I always obtained solid caustic potash of a pale yet very decided green colour, resembling that of green vitriol. This combination apparently of protoxide of iron and potash has been described under the name of ferrite of potash. It has a powerful affinity for oxygen. Thus

[6] Metallurgy, First Part, p. 15.

[7] Jahresb. 1855, pp. 401-465.

when equivalent proportions of the sulphates of protoxides of copper and iron are dissolved in water, and a solution of caustic potash or soda added to the solution, a brown-red precipitate is formed, which is a combination having the formula Cu^2O, Fe^2O^3. On treating this compound in a close vessel with ammonia, dioxide of copper alone is dissolved, and the liquor is colourless, hydrated sesquioxide of iron remaining.[8] It has the power of decomposing water: thus when a protosalt of iron is precipitated with excess of potass, and the whole is boiled, hydrogen is pretty copiously evolved, and magnetic oxide of iron formed.[9]

Sesquioxide of iron. Red oxide of iron. Fe^2O^3.—It crystallizes in the rhombohedral system. In crystals it is steel-grey, and has a bright metallic lustre; but in powder it is red. It gives a red or brownish-red streak. The minerals termed *specular iron* and *micaceous iron-ore* consist of this oxide. In thin scales, as it occurs in this ore, it transmits red light. The specific gravity of the native sesquioxide ranges from 5·191 to 5·230,[1] and that of the ignited artificial oxide was found by H. Rose to be 5·17. The artificially prepared oxide is non-magnetic, but the native crystallized oxide is slightly so.[2] It is not volatile, though the occurrence of specular iron in the craters of volcanoes might induce the belief that it was. Mitscherlich, however, showed that this mineral had not been sublimed, but generated by the contact, at a high temperature, of the vapour of water and that of sesquichloride of iron, which decompose each other, with the formation of hydrochloric acid and crystallized sesquioxide of iron.[3]

It is infusible, except at very high temperatures, and then not without the loss of oxygen and the formation of magnetic oxide. Thus, according to H. Rose, it melts in a porcelain kiln, but at the same time is reduced to magnetic oxide.[4] When sesquioxide of iron is strongly heated in contact with metallic iron, it is reduced to magnetic oxide. Thin iron wire was cut into short lengths, and put at the bottom of a wrought-iron crucible, some sesquioxide of iron was placed upon it, and then cut iron wire was introduced so as to fill up the crucible, which was enclosed in a covered clay crucible and strongly heated. When cold, the wire was found to cohere so strongly as to render it necessary to cut open the crucible with a chisel and hammer. The sesquioxide of iron was replaced by a finely crystalline black powder, which was attracted by the magnet, and yielded by assay 73·9°/₀ of iron, *i.e.* 1·5°/₀ more than in magnetic oxide.

It is easily reduced to the metallic state when heated to redness in contact with carbon, carbonic oxide, hydrogen, ammonia, or cyanogen. When reduction by any one of these agents takes place at a comparatively low temperature, the metal is left in a pulverulent state; but when the temperature is high, a coherent mass of malleable iron is

[8] Berzelius, Tr. 2. p. 674.
[9] Fremy, Ann. de Chim. et de Phys. 1844, 12. p. 365.
[1] G. Rose, Pogg. Ann. 74. p. 440.
[2] H. Rose, Anal. Chem. 1851, I. p. 121. Recently an artificial red oxide has been prepared, which is magnetic.
[3] Pogg. Ann. 15. p. 630.
[4] Ibid. Ann. 74. p. 440.

produced which may be readily forged with solid metal. It is not necessary, as we have previously seen, that there should be intimate contact between carbon and sesquioxide of iron in order to effect complete reduction.[5] Lumps of oxide of considerable size, say as large as the fist, may be entirely converted into metallic iron by exposing them, imbedded in coarse charcoal-powder, to a bright red heat during several hours. At first there is only reduction to the state of magnetic oxide of iron; and, according to Berthier, if the mass be not too considerable, it is wholly changed into this oxide before any metallic iron is formed. Subsequently metallic iron appears at the surface, and, *pari passu*, a lower oxide than magnetic oxide, namely, that of *iron scale*, is produced in the interior even to the centre.[6] In reduction by hydrogen, magnetic oxide appears to be first formed; and if the experiment be made at very low temperatures, the product will sometimes be found to consist almost entirely of magnetic oxide, in which case it will be black, and not grey.

Sesquioxide of iron is largely manufactured in the state of amorphous powder, the colour of which varies greatly according to the method of preparation. It is extensively used as a pigment in the ceramic arts, and produces tints of red, brown, and violet.[7] Thus, the following salts of sesquioxide of iron, basic sulphate, sulphate, and nitrate, yield by calcination respectively products of a very fine red, dark red, and blackish brown colour.[8] Sesquioxide of iron is also much employed in polishing plate glass, and is made for this purpose by calcining sulphate of protoxide of iron (green vitriol) at a red heat, and subjecting the residue, called *colcothar*, to trituration and levigation. The red powder sold under the name of *rouge* for polishing silver-ware is only very finely levigated sesquioxide of iron. In one specimen which I examined I detected mercury, an ingredient which should not be tolerated; for although it may lessen the labour of the polisher, it will certainly increase the wear of the plate. A beautiful micaceous variety of sesquioxide of iron may be obtained by carefully heating dried sulphate of protoxide of iron mixed with two or three times its weight of common salt. Sulphate of soda is formed, which along with any excess of common salt may be removed by washing with water. Thus prepared the oxide is stated to be well adapted for polishing. It is acted upon even by hot hydrochloric acid with difficulty.

By ignition with excess of sulphur, sesquioxide of iron is converted into sulphide with the evolution of sulphurous acid. At high temperatures it acts the part of an acid towards fixed bases. Thus, as has been previously stated, it forms fusible combinations with lime.[9] When strongly heated with carbonate of potash or soda, carbonic acid is expelled, and by the action of water on the product caustic alkali is dissolved and sesquioxide of iron left.

Sesquioxide of iron is insoluble in water or in solutions of the fixed alkalies or ammonia. It dissolves in sulphuric, nitric, hydrochloric,

[5] Metallurgy, First Part, pp. 14-18.
[6] Tr. des Ess. 2. p. 186.
[7] Brongniart, Tr. des Arts Céram. 1844, 2. p. 516.
[8] Berzelius, Tr. 2. p. 668.
[9] Metallurgy, First Part, p. 43.

and various other acids, but when crystallized or after ignition, only very slowly, even with the aid of heat. The best solvent is hydrochloric acid. In effecting solution in this acid, I have found it convenient first to reduce the oxide by heating it to redness in a porcelain crucible, closed with a cover having a hole in it through which a jet of hydrogen or coal-gas is introduced. Complete reduction takes place in the course of a few minutes, after which the metallic iron may be rapidly dissolved; and, if necessary, the protochloride of iron formed may be immediately converted into sesquichloride in the usual manner by boiling with a little chlorate of potass or nitric acid. Much time is thus saved.

On heating a bead of borax or platinum wire with a small quantity of sesquioxide of iron before the blow-pipe in the oxidizing flame, it is yellow while hot and colourless when cold; with a larger proportion of oxide it is red while hot and yellow when cold; and with a still larger addition it is deep red while hot and deep yellow when cold. In the reducing flame it becomes bottle-green; and when heated in this flame on charcoal with the addition of tin, it at first becomes bottle-green and after long blowing acquires the colour of green vitriol. With microcosmic salt in the oxidizing flame, a certain proportion of this oxide produces a bead, which is yellowish red while hot, but on cooling becomes at first yellow, then greenish, and at last colourless. With a very large addition of the oxide the bead is dark red while hot, and on cooling becomes brown red, then dirty green, and when cold brownish red. The colours disappear on cooling much sooner than in the case of borax beads. In the reducing flame with a small addition of oxide the bead does not appear changed; with a larger proportion, it is red while hot, and on cooling becomes at first yellow, then greenish, and at last reddish. Treated with tin on charcoal the bead on cooling becomes green, and at last colourless.[1]

Hydrated sesquioxide of iron.—Sesquioxide of iron combines with water, forming definite hydrates, which lose the whole of their water at a red heat. It is precipitated as a bulky reddish brown hydrate by the addition of ammonia, or caustic potash, or soda to solutions of salts containing this oxide as the base, such as the sesquichloride of iron. It retains some of the fixed alkaline precipitants which cannot be removed by washing. When first thrown down its formula is stated to be Fe^2O^3, 3HO; in this state it is readily soluble in acids, and appears perfectly amorphous under the microscope. If, however, it is kept for some time under water it becomes crystalline, is much less easily soluble in acids, and has the formula $2Fe^2O^3$, 3HO, so that it loses half the water which it originally contained.[2] When boiled in water during 3 or 4 minutes its formula becomes Fe^2O^3, HO; and after exposure to the action of water at 160° C. or 186° C., as in closed tubes, during 8 days it was found by Senarmont to become anhydrous.[3] Schiff examined a specimen of hydrated sesquioxide of iron which

[1] Plattner, Probirkunst, 1853, p. 146.
[2] Buchner, Gmelin, Handbook, 5. p. 198.
[3] Ann. de Chim. et de Phys. 1851, 32 p. 146.

had remained longer than 15 years under water at the ordinary temperature, and ascertained that it had the same formula.[4] The hydrate is much altered after exposure to the action of boiling water during 7 or 8 hours. It becomes brick-red in colour, and is hardly acted upon by strong and boiling nitric acid; and concentrated hydrochloric acid only dissolves it at the temperature of ebullition, or after prolonged contact. In the original and important paper of Mr. Graham on Dialysis are recorded some interesting observations on hydrated sesquioxide of iron. On dialysing a solution of highly basic sesquichloride of iron, he obtained an aqueous solution nearly pure of sesquioxide of iron. Water containing about 1 per cent. of this hydrate in solution has the dark red colour of venous blood. This solution may be concentrated by boiling to a certain point, when it pectizes, *i.e.* the hydrate separates and coagulates into a jelly-like mass. Coagulation in the cold is induced by traces of sulphuric acid, alkalies, alkaline carbonates, sulphates and neutral salts in general, but not by hydrochloric, nitric, or acetic acids, nor by alcohol or sugar. The coagulum is a deep red coloured jelly, resembling the clot of blood, but more transparent; once formed, either by a precipitant, or in the course of time spontaneously, without any addition having been made to the solution of sesquioxide of iron, it is no longer soluble in water, hot or cold, but readily dissolves in dilute acids. It is, in short, the ordinary hydrated sesquioxide of iron, so that there is a soluble and insoluble form of this substance in the colloidal state. Mr. Graham is of opinion that native hæmatite in mammillary concretions is colloidal. There is also a soluble meta-sesquioxide of iron, which is prepared by the prolonged action of heat upon a pure solution of the acetate. The characteristic properties of this substance, which indicate its allotropic nature, are the orange-red colour and the opalescence of its solution. It is entirely precipitated of a brown ochreous appearance by a trace of sulphuric acid, or of an alkaline salt, and is insoluble in all cold acids even when concentrated.[5]

Sesquioxide of iron and lime.—In the preceding volume[6] it was shown that this oxide and lime combine in the *dry way*, but they also combine in the *wet way*. Pelouze has described a compound of the formula $4CaO, Fe^2O^3$. It is precipitated by the addition of an excess of potash to an aqueous solution of chloride of calcium and sesquichloride of iron in the ratio of 4 equivalents to 1. It is a light, amorphous, snow-white powder, which becomes brown on exposure to the air, owing to the formation of carbonate of lime and the liberation of sesquioxide of iron. It may be kept for any length of time provided air be excluded. When first produced it is more or less brown, as a little of the sesquioxide is thrown down apparently not in a free state, which in the course of some hours afterwards enters into combination with lime, and the precipitate becomes white, though containing nearly half its

[4] L. u. K. Jahresb. 1860, p. 188.

[5] Phil. Trans. June 13, 1861, p. 208. Vid. also Péan de Saint-Gilles, Recherches sur le sesquioxide de fer modifié par la chaleur. Ann. de Chim. et de Phys. 1856. 46. p. 47.

[6] Metallurgy, First Part, p. 43.

weight of sesquioxide of iron. It is insoluble in water, whether pure or containing sugar. It is a very unstable compound, and is decomposed by carbonic acid or when boiled with a soluble carbonate. It may be boiled with caustic potash without undergoing any change.[7] I may state that some time before the publication of Pelouze's paper, Mr. Mercer, of Manchester, informed me that sesquioxide of iron and lime combined in the *wet way*.

Magnetic oxide of iron. Fe^3O^4, or $FeO+Fe^2O^3$.—It crystallizes in the cubical system. It occurs well crystallized in nature, and also as a product of various metallurgical operations, especially in the manufacture of iron. I have very often found it in furnace products, and generally in octahedrons; but I have a specimen of it from the Blaina Iron-works, Monmouthshire, in rhombic dodecahedrons, almost rivalling in beauty the well-known native crystals from Traversella. I have slags in which small octahedrons are piled continuously one upon another, so as at first sight to appear like prisms. It is black in powder as well as in mass. It gives a black streak. When crystallized it has a metallic lustre. It is opaque. The specific gravity of the native oxide ranges between 4·98 and 5·20. It is not volatile, and is fusible at very high temperatures. In certain processes in the manufacture of iron, in which jets of atmospheric air are made to impinge at a steep angle upon molten cast-iron, a large quantity of minute hollow spherical shots which are strongly attracted by the magnet fall like rain from the surrounding atmosphere. I have collected pounds of them at a time on the ground, and have found them all over my clothes, especially on the brim of the hat. These shots, however, contain silica, which is separated in a gelatinous state, by the action of hydrochloric acid, in addition to sesquioxide, and protoxide of iron. They have been analysed in the Metallurgical Laboratory of the Royal School of Mines by Mr. Smith, and found to have the following composition :—

Protoxide of iron	28·91
Sesquioxide of iron	37·44
Silica	24·10
Alumina, with small quantities of oxide of manganese, lime, and magnesia	9·55
	100·00
Metallic iron °/o	48·70

This proportion of sesquioxide would require 16·85 of protoxide of iron to form magnetic oxide, leaving 12·06 of protoxide of iron in combination with silica. Supposing the whole of the iron to be present as protoxide, and combined with silica as 3FeO, SiO^3, there would be a deficiency of silica to the amount of 2·57. The alumina was probably derived chiefly from the ashes of the coke under which the cast-iron was melted in the operation of refining. As silica decomposes sesquioxide of iron at a high temperature with the formation of tribasic silicate of protoxide of iron and evolution of oxygen, it is

[7] Ann. de Chim. et de Phys. 1851, 33. p. 5.

possible that this action may have been going on at the time of the projection of the shots, and that the oxygen liberated in consequence may have in some way determined the projection. What has been stated regarding the reduction of sesquioxide applies equally to magnetic oxide of iron. It is reduced to the metallic state by potassium or sodium at about 300° C. with a slight evolution of light and heat; whereas, at a high temperature, metallic iron completely reduces the oxides of these metals.[8] It combines with about 7 per cent. of water, forming a hydrate. It is this compound which speedily results from the action of the air on the white precipitate occasioned by the addition of a solution of potash or soda to salts of protoxide of iron. It is at first dull green, then black, and on further exposure to the air is entirely converted into brown hydrated sesquioxide. It is also immediately produced when the same alkaline precipitants or ammonia are added to solutions of salts of protoxide and sesquioxide of iron mixed in the proper ratio. Thus prepared by desiccation, it becomes an agglutinated black mass, of which the fracture is vitreous and the powder brown. It is magnetic like the anhydrous oxide. Heated in a close vessel it loses its water. Magnetic oxide is formed by boiling iron filings in excess with water and hydrated sesquioxide of iron, such as may conveniently be prepared by adding ammonia to a solution of sesquichloride of iron and well washing, but not drying, the precipitate. Water is decomposed with the evolution of fetid hydrogen, and this continues until sufficient protoxide is produced to form magnetic oxide with the sesquioxide present. The product is black pulverulent hydrate of magnetic oxide, from which the excess of metallic iron may be easily removed by levigation. When solid protochloride of iron is heated with an excess of carbonate of soda in a crucible, magnetic oxide is formed, and by washing with water is left in the state of black crystalline powder, which may be dried without further oxidation.[9] When magnetic oxide, anhydrous as well as hydrated, is put into a close vessel with a quantity of acid, say hydrochloric, not more than sufficient to dissolve the protoxide present, the latter alone will pass into solution.

Iron scale.—When iron is heated to redness as in the annealing of sheet-iron, or to a still higher temperature as in forging bar-iron, its surface becomes coated with oxide, which is in great measure detached either by bending or hammering the metal when cold, or by plunging it while hot into cold water. It is this oxide which is known as *iron scale* or *hammer slag*. It is black, opaque, slightly metallic in lustre, melts at a high temperature, and is strongly magnetic. Berzelius examined a piece of iron which had been kept in the furnace during 24 hours; it was covered with a thick crust, 3^{mm} (0·12 in.) in thickness, which on fracture was seen to consist of two distinct layers. The internal one was dark in colour, bubbly, without much lustre, and feebly attracted by the magnet. The external one presented on its outer surface a thin layer of sesquioxide, which produced a red tint; its fracture was compact, brilliant, and iron-grey in colour; it was hard, tenacious, and

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[8] Gmelin, Handbook, 5. p. 192. [9] Liebig and Wöhler. Berzelius, Tr. 2. p. 672.

more strongly attracted by the magnet than the first. These layers were separately analysed by Mosander, and the results are as follow:

	Composition per cent. Internal layer.	External layer.
Protoxide of iron	72·92	64·23
Sesquioxide of iron	27·08	35·77

But on further analysing apart the outer and inner halves of the *external* layer, Mosander found that the proportion of sesquioxide of iron diminished from without inwards; whereas the *internal* layer was homogeneous throughout, and in composition might be represented by the formula $6FeO, Fe^2O^3$.[1]

The following experiments on the formation of iron scale have been made in my laboratory by Mr. Smith. The iron taken for the experiments was a piece of wrought-iron bar, 1 in. square, 4¼ in. in length; and 6 pieces of flat hoop-iron, 4¼ in. in length, 1⅛ in. in width, and $\frac{1}{18}$ of an in. in thickness, piled up, and kept apart by transverse pieces of stout iron wire. The whole were placed upon fire-brick, and heated in a muffle, the temperature being slowly increased from a cherry-red to a full-red heat. At the end of 2½ hours one of the pieces of hoop-iron was taken out, and when cold the iron scale examined. This scale was easily detached from the surface of the iron, and found to consist of three layers:—

1. *Outer layer.*—Colour reddish grey-black; lustre dull, and in some places feebly metallic; brittle, very thin, and raised in blisters in some places; not attractable by the magnet; colour of fine powder, purple red-brown.

2. *Middle layer.*—Colour greyish-black; lustre metallic; fracture bright, and fibro-crystalline; the fibres arranged transversely to the surfaces; strongly attractable by the magnet; powder black; thickness about $\frac{1}{32}$ of an inch; it forms the part of which the ironscale is chiefly composed.

3. *Inner layer.*—Resting on and in contact with the surface of the iron, and forming a thin, black, crystalline layer, covered with numerous minute octahedral crystals. It was easily detached from the iron on bending, when the surface of the iron was also found to be coated in places with these minute crystals; the powder was black, and attractable by the magnet, but less so than No. 2.

Portions of each of the three layers were carefully separated from each other, and found to have the following percentage composition:—

	I. Outer layer.	II. Middle layer.	III. Inner layer.
Protoxide of iron	1·20	59·49	73·81
Sesquioxide of iron	98·80	40·51	26 19
	100·00	100·00	100·00
Iron %	70·09	74·64	75·74
Formula	Fe^2O^3	$3Fe^2O^3 + 10FeO$ or $3Fe^3O^4 + 7FeO$	$Fe^2O^3 + 6FeO$ or $Fe^3O^4 + 5FeO$

[1] Berzelius, Tr. 2. p. 674.

The experiment was continued, the heat of the muffle being increased from full-red to a yellowish-white heat; and at the end of 2 hours another of the pieces of hoop-iron was taken out, and the scale examined as before. It consisted of three layers, resembling in physical and external characters those previously described. The outer and middle layers only were examined, and had the following composition:—

	I. Outer layer.	II. Middle layer.
Protoxide of iron	0·69	52·01
Sesquioxide of iron	98·63	47·67
	99·32	99·68
Iron °/o	69·58	72·39
Formula	Fe^2O^3	$2Fe^2O^3 + 5FeO$ or $2Fe^3O^4 + 3FeO$

The furnace was now allowed to cool down, and on the following morning the remaining pieces of iron were taken out of the muffle. The *inner scale*, detached from one of the pieces of hoop-iron, had the following composition:—

Protoxide of iron	53·23
Sesquioxide of iron	46·77
	100·00
Iron °/o	74·14
Formula	$2Fe^2O^3 + 5FeO$ or $2Fe^3O^4 + 3FeO$

The scale on the square iron bar was similar in external characters to that previously examined, and was chiefly composed of three layers. The *outer* and *middle layers* had the following composition:—

	I. Outer layer.	II. Middle layer.
Protoxide of iron	0·32	40·94
Sesquioxide of iron	99·68	59·00
	100·00	100·00
Iron °/o	70·02	73·18
Formula	Fe^2O^3	$2Fe^2O^3 + 3FeO$ or $2Fe^3O^4 + FeO$

Velvet scale.—The bar of iron, at the end which had been exposed to the highest temperature at the back of the muffle, was coated with a scale about $\frac{1}{16}$ of an inch in thickness, which had a velvet lustre, mammillated structure, and crystalline fracture; the under surface was dull, and showed imperfect crystals; powder reddish dark-brown, and entirely taken up by the magnet. It is readily soluble in hydrochloric

acid, leaving a trace of flocculent silica, and had the following composition per cent. :—

Protoxide of iron	10·73
Sesquioxide of iron	89·27
	100·00
Iron °/₀	65·93
Formula	$4Fe^2O^3 + FeO$ or $Fe^3O^4 + 3Fe^2O^3$

A piece of hoop-iron, used in an experiment on Dinas-brick, on withdrawal from the muffle, was found to be completely oxidized, but it still retained its shape. It was converted into a black, vitreous, compact, brittle scale; the external surface had a feebly metallic lustre, and the powder was attractable by the magnet. It had the following composition :—

Protoxide of iron	54·89
Sesquioxide of iron	37·49
Silica (by difference)..................	7·62
	100·00
Iron °/₀	68·94

Ferric acid. FeO^3.[2]—Fremy, Denham Smith, and H. Rose have investigated this acid, and agree as to its formula. It is not known in an isolated state. Its salts are characterised by an intense purplish red colour. Ferrate of potash is very soluble in water, to which it communicates a fine violet red tint. It is precipitated by excess of potass, when it appears black. The solution of this salt spontaneously decomposes, with the evolution of oxygen, the precipitation of sesquioxide of iron, and the liberation of potash; and when it is heated to boiling, this reaction is instantaneous. The presence in it of finely suspended matter, such as sesquioxide of iron, hastens decomposition, as is also the case with oxygenated water. What is singular, the hypochlorites, according to Fremy, render ferrate of potass more stable—so much so, that a solution of this salt mixed with alkaline hypochlorite is only very slowly destroyed by boiling. Chlorine in excess decomposes ferrate of potash, and so does ammonia, which disengages nitrogen and precipitates sesquioxide of iron. All strong acids decompose it, the ferric acid being *instantly* resolved into oxygen and sesquioxide of iron, which is not the case with permanganate of potass.

By the addition of hydrochloric acid to ferrate of potash, chlorine and sesquichloride of iron are produced. Organic matters decompose it, so that a solution of ferrate of potash cannot be passed through a paper filter. Ferrate of potash may be prepared by the following processes. A Hessian crucible containing 5 grammes of filings of pure iron is

[2] Recherches sur les Acides Métalliques. Par M. Ed. Fremy. Ann. de Chim. et de Phys. 1844, 12, p. 364. I have freely availed myself of this paper, and adhered as far as practicable to Fremy's language.

heated to redness, when 10 grammes of the powder of fused nitre are thrown in; most lively action immediately occurs, and as a portion of the contents is thrown out, the operation requires care; the crucible is then covered and left to cool. A violet red mass containing a large amount of ferrate of potass is thus procured, and may be easily detached. This is one of the methods recommended by Fremy, who particularly insists upon the necessity of following precisely the directions here given. Mr. Denham Smith[a] recommends the subjoined process as having been uniformly successful in his hands:—"Wash the *ferri sesquioxidum* of the shops with boiling water until free from sulphate of soda, dry and ignite at a low red heat; this furnishes a very pure oxide of iron and in a state of minute division; one part of this is to be intimately mixed with four of dried nitre, reduced to fine powder; place this mixture in a crucible of about twice the capacity of the bulk of the mixture, lute a well-fitting cover on, making a few small holes in the lute to allow the escape of gas, and ignite at a *full red* heat for about an hour, if six or eight ounces are made: the time of ignition depends much on the quantity prepared, and the temperature should never be raised above a full red. When well prepared it presents the appearance of a dark reddish-brown porous mass, rapidly deliquescing on exposure to the air, so that I have found it advantageous to powder it whilst still warm, when it may be preserved for use in a well-stoppered bottle, apparently for any length of time." Ice-cold water is recommended to be used in dissolving it. Ferrate of potash resulting from the action of nitre upon iron is, according to Fremy, always mixed with some peroxide of potassium, which decomposes immediately the mass is treated with water. Ferrate of potass is formed by the long continued heating of a mixture of potash and oxide of iron in a current of air, or, better still, of oxygen; by exposing a mixture of peroxide of potassium and sesquioxide of iron to a red heat in an iron crucible; and by calcining in an iron crucible a mixture of sesquioxide of iron, nitre, and potash. It may be made in the *wet way* by passing chlorine not too rapidly through a strong solution of potass containing hydrated sesquioxide of iron in suspension. Fragments of potass should be added from time to time, as the ferrate forms only in very alkaline solutions. The liquor becomes hot, and a considerable quantity of oxygen is evolved. Ferrate of potash has been obtained by Poggendorff in microscopic crystals on a plate of cast iron immersed in a solution of 1 part of potash and 4 parts of water, and employed as the positive electrode in a current from six cells of Grove's battery, a plate of platinum being used as the negative electrode. The platinum is contained within a porous cell filled with solution of potash and depressed in the first-named solution. Ferrate of soda may be easily produced by this process, but not by the *dry method;* it is not precipitated by excess of soda. Its solution is red, and closely resembles ferrate of potash. Ferrate of baryta is precipitated by the addition of nitrate of baryta, or chloride of barium, to a solution

[a] Phil. Mag. 1843, 23. p. 219.

of ferrate of potash; it has a fine purplish-red colour, is insoluble in water, and is much more stable than the soluble ferrates. It may be boiled for some time in water without decomposing. Organic matters act but slightly upon it, and it may even be washed on a paper filter. Strong acids destroy it, forming salts of iron and baryta, and liberating oxygen. Dilute acetic acid dissolves it, yielding a fine red solution, the colour of which disappears on the application of heat, acetate of sesquioxide of iron being produced and oxygen set free. Ferrate of potash yields no precipitate with salts of strontia, lime, or magnesia. It is decomposed by salts having metallic oxides as bases, which are capable of passing to a higher degree of oxidation, such as manganese, nickel, cobalt, etc., higher oxides of those metals being thrown down. Mr. Denham Smith obtained emerald-green solutions of salts of potash and soda, in which he supposed the iron was in a lower state of oxidation than in ferric acid. A less proportion, about half, of nitrate of potash appeared to be the condition favourable to the production of the green salt, which was much more stable than the ferrate, and remained after the destruction of the latter by boiling.

Fremy was the first to recognize distinctly the nature of ferric acid, though it had been known long before that the product of the action of nitre on iron at a red heat communicated a deep red colour to water. Stahl, it is stated, was aware of this fact.[4] In the excellent translation by Dr. Lewis of the fine old German work on Chemistry by Neumann is the following note by the translator:—" *Iron with Nitre.* A part of the Iron is thus rendered soluble in water along with the alcalized Salt. A mixture of equal parts of Iron filings and Nitre, injected into a strongly heated crucible, and, after the detonation, thrown into water, tinges the liquor of a violet or purplish-blue colour. This solution, however, is not permanent. Though the liquor at first passes through a filter without any separation of the Iron, yet, on standing for a few hours, the metal falls to the bottom in form of a brick-coloured powder. It is pretty singular, that volatile alcalies instantly precipitate the Iron from this fixed alcaline solution."[5]

Iron and Water.

At the ordinary temperature water has no action upon iron, even in the most finely divided state, provided air be excluded; but the pulverulent metal decomposes water far below 100° C. Experiments on this point have been made by Mr. Dick in my laboratory. It was found that with iron reduced from sesquioxide by hydrogen at a low temperature decomposition begins at 55° C., and that the action increases as the temperature rises. Hydrogen is evolved and magnetic oxide of iron formed. Iron thus reduced, which was ascertained to be

[4] Gmelin, Handb. 5. p. 265.

[5] The Chemical Works of Caspar Neumann, M.D., Professor of Chemistry at Berlin, F.R.S., etc. Abridged and methodized, with large additions, containing the latest discoveries and improvements made in Chemistry and the arts depending thereon. By William Lewis, M.B., F.R.S. London, 1749, 4to. p. 73.

perfectly free from oxide, was boiled in water, and the product obtained was shaken with a perfectly neutral solution of chloride of copper (CuCl) and chloride of sodium. Some metallic iron which had escaped oxidation dissolved, and there remained a black substance, which was attracted by the magnet, and dissolved without effervescence in hydrochloric acid, yielding a solution of protochloride and sesquichloride of iron. The solution above mentioned may be conveniently employed to determine whether reduction by hydrogen is complete; as the product readily and wholly dissolves when free from oxide, which is insoluble in this solution. Iron reduced by hydrogen was found on the application of heat to decompose water in the presence of potash and ammonia.

In order to demonstrate that water at the ordinary temperature has no action on iron when air is excluded, the following experiment was made by Mr. Dick. A current of pure hydrogen was passed through a glass tube drawn out at both ends, and containing a clean bright strip of iron together with some distilled water previously boiled. The tube was then hermetically sealed, and first at the end furthest from the gas generator. This was done in April, and not the slightest indication of rust was noticed in October following, nor indeed for a year or two afterwards. When iron is exposed to the conjoint action of air and aqueous moisture at ordinary temperatures, oxidation or rusting occurs; but not, it would seem, unless there is actual deposition of liquid water upon the surface of the metal. In the Museum of Practical Geology are numerous specimens of iron, which have been exposed in glass cases during the last 12 years; and though the cases have been frequently opened, the fractured surfaces are as bright as they were when first produced. The Museum is heated by hot water, and the condensation of moisture upon these objects has been thereby effectually prevented. It is oxygen in solution in water which appears to determine rusting in the first instance; but when the action is once commenced, it proceeds in moist air without the further deposition of water. The presence of various foreign matters, even in minute proportion, such as sulphuretted hydrogen, chlorine, hydrochloric and acetic acids, induces rusting in moist air, though no liquid water may come in contact with the surface of the metal; but carbonic acid in small quantity and ammonia are stated to be without action in this respect.[6] It is asserted that the rust of iron, which is hydrated sesquioxide, always contains ammonia, and this is explained by the decomposition of water due to the contact of the oxide and metallic iron, the oxygen combining with the latter, and the hydrogen, in part at least, combining in the nascent state with the nitrogen of the air. But if hydrated sesquioxide of iron have any special power of retaining ammonia, or, as Berzelius alleges, of combining with it, then, in order to establish the formation of this alkali in the manner described, it must be shown that rust of iron has not absorbed it from the atmosphere which invariably contains it. When iron is immersed

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[6] Bonsdorff, Répertoire de Chimie, 4. p. 171. Quoted from the Ann. der Chem.

to some depth in water, of which the surface is exposed to the air, black hydrated magnetic oxide is produced; because, according to Wöhler, the atmospheric oxygen in this case slowly reaches the metal through the medium of the water, and the hydrated sesquioxide as it is slowly generated induces the iron to decompose water and form protoxide of iron, with which the sesquioxide combines. This may be an explanation, but it appears to me to be scarcely more than an expression of the fact. Aqueous solutions of potash, soda, and ammonia have been found to preserve iron from rusting, provided they be not too dilute. Payen states that 1 part by measure of water saturated with hydrate of potash at 22° C. suffices to communicate this protective action to 2000 parts by measure of water; and that the same is true of a solution consisting of 1 part by measure of a saturated solution of carbonate of soda diluted with any number of parts by measure of water not exceeding 54. The alkali loses its protective power when converted into bicarbonate. According to Hall, water containing even not more than $\frac{1}{4}$ of its volume of lime-water preserves iron from rusting.[7] It is stated that, in the absence of atmospheric air, carbonic acid in solution in water dissolves iron with the disengagement of hydrogen gas. Carbonate of protoxide of iron is formed and retained in solution by excess of carbonic acid; and when this is driven off, it is precipitated and, with access of air, is gradually converted into hydrated sesquioxide of iron.[8]

C. von Hauer found that by passing a current of carbonic acid during several hours through water at the ordinary pressure of the atmosphere, in which very finely divided iron was suspended, such as is produced by heating to redness oxalate of protoxide of iron or by reducing oxide of iron by hydrogen, the solution contained 0·091°/₀ carbonate of protoxide. This solvent action appears to be prevented by the presence of alkaline carbonates.[9]

Zinc, in contact with iron, retards rusting; and tin, on the contrary, promotes it. The late Mr. Richard Phillips informed me that he had made precise comparative experiments confirming this statement, by exposing to the conjoint action of air and water sheets of iron coated respectively with zinc and tin, and partially denuded by scraping so as to lay bare a clean surface of iron.

The common practice adopted in order to preserve polished iron bright is to smear the surface with sweet oil or fatty substances, or to apply a coating of some kind of varnish. Many years ago a friend, who was engaged in the manufacture of highly polished rolls for exportation, informed me that several had been returned upon his hands in consequence of having been delivered in a rusty state, and that he had lost in carriage only not an inconsiderable sum. He had taken the precaution to coat them well with fat and afterwards wrap them carefully in matting; and yet rusting occurred. We tried

[7] Gmelin, Handb. 5. p. 185. I have not consulted the original authorities for the statements immediately preceding.

[8] Golfier-Besseyre, L. u. K. Jahresb. 1851, p. 358.

[9] L. u. K. Jahresb. 1860, p. 189.

several experiments together on this subject, and found common rosin melted with a little Gallipoli oil and spirits of turpentine, to answer well as a protective application. The proportions should be such as to form a coating, which will adhere firmly, not chip off, and yet admit of being easily detached by cautious scraping. I do not remember what these proportions are, but they may be speedily found by experiment. The mixture proved an effectual preventive of rust during long sea voyages, and no further loss was sustained by my friend. The method may, for aught I know, have been long previously in use; and my only motive in now publishing it is, that it may still be unknown to some persons who may apply it to their own advantage.[1]

At a red heat or higher temperatures iron decomposes water with rapidity, hydrogen being evolved and magnetic oxide (Fe^3O^4) in small octahedral crystals produced. I have seen beautifully crystallized magnetic oxide formed by this process under some accidentally favourable conditions. The higher the temperature the finer are the crystals, provided the current of steam be not too strong, and carefully regulated.

Iron and Sulphur.

Iron has a strong affinity for sulphur. Combination between these elements takes place at a red heat, and is attended with bright incandescence. A very beautiful, though common, experiment is to heat a bar of iron in a smith's fire until it begins to burn with the emission of sparks, then to withdraw it and touch it with a roll of sulphur, which causes it to glow most vividly and immediately to melt into drops of sulphide. There are several definite sulphides of iron. The following experiments have been made in my laboratory with respect to the direct formation of sulphide of iron in the *wet way*. The mixtures were enclosed in hermetically sealed glass tubes, and examined long afterwards. Iron filings in a solution of polysulphide of potassium were washed with water and dissolved completely in hydrochloric acid, evolving only a trace of sulphuretted hydrogen.

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[1] "*Strange Accident in Portsmouth Dockyard.*—In the north-east portion of Portsmouth Dockyard, and exactly opposite the grounds which enclose the residence of the Admiral-Superintendent, is a large iron salt-water tank, standing on lofty iron columns over some stores of oak planking. It is 160 ft. long, 40 ft. wide, and 5 ft. deep, and is kept filled with salt water to assist in quenching any fire which might break out in its neighbourhood. About half-past eleven on Wednesday evening an alarm was given that it had burst, and that the water which rushed out was committing great ravages upon the roadways and the Admiral-Superintendent's grounds and gardens adjoining. It was found on examination that about 70 ft. of the iron plates forming one side of the tank had given way, and had been hurled with the water into the roadway. The tank was built up of cast-iron flanged plates, fastened together with bolts, nuts, screws, etc., in the usual manner. Some of the plates have been separated at the fastenings, the nuts having been torn off the screw ends of the bolts by the pressure of the water. In other instances the iron plates have been broken through diagonally, like pottery-ware. The weight of the water in the tank was calculated at 890 tons, and the pressure against the side of the tank which has given way at about 50 tons. An inspection of the broken parts of the tank disclosed the somewhat extraordinary fact that the wrought-iron tie-rods in the interior of the tank were very much eaten away at their junction with the cast-iron plates, where they had been submerged in the salt water."—*Times, June* 19, 1863.

A strip of clean sheet-iron was immersed in a solution of polysulphide of potassium (Feb. 11, 1853), and the mouth of the bottle was tied down with sheet indiarubber to exclude air. In January, 1863, the bottle was opened, when the following changes were found to have occurred:—Pale yellow, semi-transparent crystals of sulphur had collected at the bottom of the solution. The iron was coated with a substance which externally had a black, dull, and mammillated appearance; on bending the iron it was found to be nearly corroded through, except a thin portion in the centre, and converted into a compact, feebly metallic, bronze-coloured sulphide, not attractable by the magnet. The outer black film was carefully removed, the sulphide washed rapidly with water, dried between bibulous paper, and examined by Mr. Smith. The powder is black, but changes slowly to brown when kept in a closed glass tube. It is slowly acted upon when digested with cold water, but hot water dissolves out quickly an alkaline sulphide. It is decomposed by hydrochloric acid, with the evolution of sulphuretted hydrogen, and the separation of a small quantity of sulphur. Dried at about 110° C., it lost 5·00°/₀ of water, and the powder appeared to be unchanged. It contained, per cent.:—

	I.	II.	Calculated dried at 110° C.
Iron..................	52·68	52·60	55·41
Sulphur	29·90	..	31·48

Supposing the iron and sulphur to exist as protosulphide of iron, 55·41 of iron would require 31·64 of sulphur to form FeS. Potassium was also found to be present. Owing to the small amount of substance collected, no further examination could be made; and as powdered fused sulphide of iron is acted upon by boiling in solution of potash with the formation of alkaline sulphide, it is doubtful in what form the potassium exists.

A strip of bright iron which had been immersed in a solution of hyposulphite of soda (NaO, S^2O^2) was quite black. Hydrochloric acid dissolved the black coating with the evolution of sulphuretted hydrogen, so that sulphide of iron had been produced. Sesquioxide of iron in the state of red hæmatite in coarse and fine powder had undergone no change.

Lowest sulphide. Fe^8S.—This low sulphide has been received on the authority of Arfvedson, who describes it as a blackish grey powder, which rubbed against a hard substance produces a grey metallic streak. It contains 6·67°/₀ of sulphur. The gas evolved from it by the action of dilute acids consists of 7 volumes of hydrogen to 1 of sulphuretted hydrogen. It is made by passing hydrogen over disulphate of sesquioxide of iron ($2Fe^2O^3, SO^3$), heated to redness: water, sulphurous acid, and a large quantity of sulphuretted hydrogen escape. Sulphur should also result from the reciprocal action of the last two of these products.

Disulphide of iron. Fe^2S.—This was also discovered by Arfvedson. In external characters it exactly resembles the last sulphide, and is prepared in the same manner by substituting anhydrous sulphate of protoxide of iron for disulphate of sesquioxide. It is strongly attracted

by the magnet. It dissolves in dilute acids with the evolution of hydrogen and sulphuretted hydrogen in equal volumes. Both this and the former sulphide when heated to redness in a current of sulphuretted hydrogen are converted into a higher sulphur of the same composition as native magnetic pyrites.

Protosulphide of iron. FeS.—This sulphide may be formed by heating together sulphur and iron. It may be made on a large scale by heating thin wrought-iron scrap to redness in crucibles and dropping in sulphur from time to time, taking care to prevent access of air as much as possible. The waste scrap which is largely produced in Birmingham by button-makers is extremely suitable and indeed extensively used for the purpose. It consists of thin sheet-iron riddled with holes punched out in making "button blanks." It is, however, not easy to prepare a definite protosulphide by this process, even by re-melting with sulphur. It is apt to contain an excess of iron, and, therefore, by the action of dilute acids to evolve free hydrogen in addition to sulphuretted hydrogen. To prevent this excess, it is recommended that the temperature at which the process is conducted should not be sufficient to melt the sulphide after its formation. In this case hoop or sheet-iron of some thickness must be used, in order that when cold the scale of sulphide adherent to the metal may be detached by bending the latter backwards and forwards. If, on the contrary, there is excess of sulphur, a sulphide of iron is obtained, which on solution in dilute acids yields a residue of sulphur.[2] Protosulphide of iron prepared by Mr. Hochstätter in my laboratory, according to the directions of Berzelius, contained 60·63°/₀ of iron, *i.e.* 3°/₀ less than definite protosulphide; the powder was feebly attracted by the magnet. On the other hand, protosulphide made by Mr. Weston also in my laboratory in the usual manner contained 70·1°/₀ of iron, *i.e.* 6·5°/₀ more than definite protosulphide; the powder was not attracted by the magnet. Mr. Hochstätter prepared sulphide of iron containing 62·32°/₀ of iron, by dropping sulphur on thin hoop-iron heated to bright redness in a crucible, and allowing the product to cool therein. The product was finely pulverized, and remelted with excess of sulphur, and again left to cool in the crucible; and this second product was again treated in a similar manner. Mr. Weston poured the molten sulphide into an ingot-mould, whereby, no doubt, loss of sulphur was occasioned. Protosulphide of iron is left when bisulphide of iron (FeS^2) is exposed to a strong red heat in a covered crucible, half of the sulphur being driven off. It may be formed by suitably heating together bisulphide of iron, which is found abundantly in nature, and metallic iron in the right proportions; and, when it is only required for the generation of sulphuretted hydrogen intended for the precipitation of certain metals from solution, this method may be conveniently adopted on the score of economy. Sulphuretted hydrogen is largely consumed with this object in certain metallurgical processes, and as the presence of free hydrogen does not interfere with its action, it is immaterial

[2] Berzelius, Tr. 2. p. 680.

whether the sulphide of iron, from which it is prepared, is very definite in constitution or not.

Thus prepared, protosulphide of iron is very brittle, uneven in fracture, coarsely granular in structure and not crystalline, dark bronzy grey in colour, very feebly metallic in lustre, and not attracted by the magnet. It fuses at a red heat, and when melted is very liquid, but does not, like galena, permeate the substance of clay crucibles. It is fixed and undecomposable, if air be excluded, at the highest temperatures. In dry air it suffers no change, but in moist air absorbs oxygen with the development of much heat, and is slowly converted into sulphate of protoxide of iron. It readily dissolves in dilute acids with the evolution of sulphuretted hydrogen.

Protosulphide of iron is precipitated as a black, amorphous, flocculent substance by the addition of sulphide of ammonium or monosulphide of potassium or sodium to neutral aqueous solutions of protosalts of iron. It is not redissolved by an excess of the precipitant; yet, under certain conditions, a deep green transparent liquor is produced, which, on standing a short time, loses its green colour and deposits black flocks of protosulphide. Thus, in the preparation of artificial ultramarine, in washing on a filter the product obtained in the first instance in the usual manner by heating a mixture of kaolin, carbonate of soda, and sulphur, a deep green, bright solution passes through, which soon afterwards acquires the brownish yellow colour characteristic of a solution of alkaline sulphide containing more sulphur than monosulphide. Bunsen in his admirable paper on the Pseudo-volcanic Phenomena of Iceland particularly notices this fact. "No one," he writes, "who is familiar with analytic investigations can be ignorant of the facility with which these bodies [alkaline polysulphides] dissolve slight traces of protosulphide of iron with a green tint, and then again are able to deposit it under peculiar circumstances."[3] The green solution, however, has been supposed by H. Rose to contain a sulphide of iron of a much higher degree of sulphuration than protosulphide of iron. Perhaps this solvent action may one day tend to explain the occurrence of gold in a state of fine division in certain varieties of iron-pyrites, which there is reason to suppose have been deposited from solution, the sulphide of gold being, as is well known, a powerful sulphur acid which forms soluble salts with alkaline sulphides. Precipitated protosulphide of iron is described as a hydrate, but I am not aware whether the existence of such a definite compound has been established. The same variety of sulphide is formed by the action of sulphuretted hydrogen water or aqueous solutions of alkaline polysulphides on metallic iron, or by the admixture of iron filings, sulphur, and water. The old so-called artificial volcanoes of Lemery were made by burying such a mixture in large quantity at a slight depth below the surfaçe of the ground. After the lapse of several hours the mass, it is stated, may become incandescent. A mixture of iron filings and sulphur moistened with water absorbs oxygen with

[3] Chemical Memoirs and Reports. Cavendish Society. 1848, p. 341.

great rapidity, sulphate of protoxide of iron being formed. It was such a mixture that Scheele used in his experiments on the composition of atmospheric air. It is also produced by contact of organic matters, such as leaves, etc., with a solution of sulphate of protoxide of iron. It oxidizes rapidly when exposed to the air, with the formation of hydrated sesquioxide of iron, water, and some sulphuric acid, and the liberation of sulphur. The action is energetic, and is attended with the evolution of so much heat, that when the mass is considerable, inflammation, it is stated, may take place. As might be anticipated, it dissolves much more rapidly in dilute acids than the sulphide prepared by the dry way. It decomposes the salts of cadmium, lead, copper, and silver, converting these metals into sulphides.[4]

When protosulphide of iron is strongly heated with metallic iron, well melted apparently homogeneous products are obtained, contrary to what might have been inferred from the results of similar experiments with disulphide of copper and metallic copper. Sulphide of iron was prepared by heating together thin sheet iron and sulphur; the compound was not attracted by the magnet in the slightest degree, and had precisely the same appearance as definite protosulphide, though it was found to contain only 29·9% instead of 36·36% of sulphur, the proportion in protosulphide. Its composition might, therefore, be represented by the formula $Fe^2S + 2FeS$. The following experiments were made of melting together under plate glass in a clay crucible fine iron wire cut into short pieces with this sulphide of iron :—

1. Iron wire	1920 grains.
Sulphide of iron in powder containing 29·9% of sulphur	960 ,,

A well melted product was obtained with some black vitreous slag on the top; it was highly crystalline and appeared homogeneous throughout; the loss in weight was 80 grains. If there had been no loss, it would have contained 9·96 of sulphur.

2. Iron wire	1440 grains.
Sulphide of iron (same as used in the first experiment)	1440 ,,

The product was well melted, covered with black slag, and crystalline like the preceding, though not in a less degree; the loss in weight was 100 grains. If there had been no loss, it would have contained 14·95% of sulphur. In neither case was there any indication of separation into two layers. Thus sulphide of iron seems to dissolve in iron in very variable proportions.

Protosulphide of iron exposed to the action of hydrogen at a high temperature.—It is not decomposed when heated in hydrogen.

Protosulphide of iron exposed to the action of the vapour of water at a high temperature.—Heated to redness in a current of steam, it is decomposed with much greater energy than disulphide of copper; hydrogen in large quantity and sulphuretted hydrogen are disengaged, and a black substance remains which is partially attracted by the magnet. Regnault found that in operating upon 4 grammes (about 60 grains)

[4] Anthon. Gmelin, Handb. 5. p. 230.

in a glass tube during 3 hours only half the sulphur was removed. The free hydrogen results from the decomposition of the water by the protoxide of iron formed in the first stage of the reaction.[5]

Protosulphide of iron heated with carbon.—Heated very strongly in contact with charcoal, it parts with a small quantity of sulphur, which probably escapes in the state of bisulphide of carbon.[6] The following experiments on this subject have been made by Mr. Hochstätter in my laboratory. The protosulphide of iron operated on was the same as referred to in p. 31, and contained 60·63% of iron, *i. e.* 3% less than in the definite compound FeS. Of this sulphide 250 grains were heated under a layer of powdered charcoal, in a covered brasqued crucible, to strong whiteness, during 2½ hours. The button, which had been perfectly melted, weighed 230 grains; it had a dark bronze-coloured crystalline fracture, was magnetic, and dissolved readily in hydrochloric acid, with copious evolution of sulphuretted hydrogen. At the bottom of this button there was a globule which weighed 12 grains, and had the following characters:—It was hard, brittle, silver-white in fracture, and strongly magnetic; it partially dissolved in strong boiling hydrochloric acid, sulphuretted hydrogen and hydrogen being liberated, and a black powder remaining. This powder was boiled with nitro-hydrochloric acid, when a white powder was obtained which dissolved completely by boiling in a solution of carbonate of soda, and which therefore was silica. The experiment was repeated twice, when the same products were obtained. The large buttons and small globules from each experiment were examined analytically, and the results were as under:—

No. of experiment.	Weight of protosulphide taken.	Weight of button with globule.	Weight of globule.	Loss of weight per cent.	Composition of button per cent.		Iron per cent. in globule.
					Iron.	Sulphur.	
	grs.	grs.	grs.				
1	250	230	12	8	66·04	not deter.	87·26
2	200	165[7]	not weighed	17·5	66·11	do.	not determ.
3	160	144	do.	10	66·25	33·55	do.
					mean. 66·13		

Exp. 4. An intimate mixture of 1500 grains of protosulphide of iron, with a considerable excess of charcoal, was exposed, in a covered brasqued crucible, during 3 hours to a white heat. The product consisted of small globules of the sulphide diffused through charcoal; these globules being magnetic, were separated from the charcoal by the magnet, and then remelted in a plumbago crucible into a single button. At the bottom of this button were several globules, as in the preceding experiments. The button contained 67·09% of iron. The globules contained 89·53% of iron, and 9·41 of silicon; they evolved

[5] Regnault, Ann. des Mines, 3. s. 11. p. 45.

[6] Berthier, Tr. 1. p. 488, and 2. p. 191.

[7] The whole was not collected.

both sulphuretted and free hydrogen by digestion with hydrochloric acid.

The composition of the button may be represented by the formula $Fe^2S+6FeS$, from which the calculated percentage composition would be iron 66·66% and sulphur 33·34%.

Taking the mean proportion of iron of the first three experiments, the loss of sulphur on 100 parts of the original protosulphide was 8·32%, and on 100 parts of sulphur 21·13.

Protosulphide of iron heated with sesquioxide of iron.—There is no separation of metallic iron when protosulphide of iron is heated, even at very high temperatures, in admixture, in any proportions, with sesquioxide. Berthier supposed that the sesquioxide was reduced to protoxide, with the formation of sulphurous acid and oxysulphide of iron: but this supposition has been proved incorrect, as will appear from the following experiments made in my laboratory by Mr. Hochstätter. Artificial sesquioxide of iron and protosulphide of iron, prepared by fusion, and containing a little excess of sulphur, viz. 3%, were employed:—

Ratio of mixture.	Sulphide of iron in grains.	Oxide of iron in grains.
1. $FeS + 10\,Fe^2O^3$	11	200
2. $FeS + 5\,Fe^2O^3$	22	200
3. $2\,FeS + 3\,Fe^2O^3$	88	240

The sulphide and oxide of iron were intimately mixed, and the mixture was heated in a covered clay crucible enclosed in a covered graphite crucible, the space between the two being filled with pounded burnt fireclay. The results of these experiments are as follow:—

No. 1. Heated during an hour at gentle redness. The product was a sintered slightly coherent mass, which was easily and completely detached from the crucible. It was wholly attracted by the magnet. It contained only a very small quantity of sulphur. The loss in weight was 8 grs. There was an excess, it will be borne in mind, of 3% of sulphur in the sulphide of iron employed in these experiments, so that the ratio between the sulphur and oxygen was not exactly that indicated by the formula. The experiment was repeated with 300 grs. of oxide of iron instead of 200 grs. The product was similar in appearance to that of the first experiment, but did not retain any trace of sulphur. It yielded, by wet assay, 70·7% of iron, *i.e.* only 1·7% less than pure magnetic oxide of iron. It contained a little silica. The following formula will explain the reaction:—

$$FeS + 10\,Fe^2O^3 = 7\,Fe^3O^4 + SO^2.$$

No. 2. The same temperature was employed. The product was a fritted mass, easily removable from the crucible, and attracted by the magnet. It retained a considerable quantity of sulphur.

No. 3. The mixture was subjected to a strong red heat during an hour. The product was a melted black mass, vitreous in fracture, and having small particles of sulphide of iron disseminated through it. The clay crucible was much acted on.

Protosulphide of iron heated with sulphate of protoxide or sesquioxide of iron.—It is decomposed when heated with a sulphate of the same metal, sulphurous acid being copiously evolved; and if the mixture be in suitable proportions, neither sulphuric acid nor sulphur will be found in the residue. For example, according to Berthier, this result is obtained by gradually heating to whiteness 2·4 grms. of protosulphide of iron with 13·2 grms. of anhydrous bisulphate of sesquioxide (Fe^2O^3, $2SO^3$), *i.e.* in the ratio of 1 to 3 equivalents.

Protosulphide of iron heated with protoxide of lead.—The following results are due to Berthier.[8] To scorify 1 part by weight of protosulphide of iron 30 parts of litharge are required, and the iron is only oxidized to the *minimum* :—

	Ratio of mixture in grammes.			
	1.	2.	3.	4.
Protosulphide of iron	10	10	10	10
Litharge	60	125	250	300

1. The product was a pasty, scoriaceous mass, metalloïdal grey in colour,[9] and strongly magnetic: it consisted of sulphide and of protoxides of iron and lead.

2. The product consisted of a very liquid, metalloïdal black, opaque mass, bright in fracture and very magnetic, and of 36 grms. of metallic lead.

3. The product consisted of a compact, vitreous, transparent, fine resin-red coloured mass, and of 67 grms. of lead.

4. The product was similar in appearance to the last, but free from combined sulphide, and 70 grms. of lead were separated.

If, as Berthier inferred, the iron is only converted into protoxide, it may fairly be asked, on what did the magnetic property of Nos. 1 and 2 depend? The fine red colour, which is said to have characterized the products in Nos. 3 and 4, seems to point to the conclusion that the iron was partially, if not wholly, converted into sesquioxide.

Protosulphide of iron heated with carbonate of potash or soda.—At a red heat protosulphide of iron, in admixture with once or twice its weight of carbonate of potash or soda, forms a very liquid product, which solidifies on cooling into a crystalline, homogeneous, black, and very magnetic mass. When this compound is digested in water, alkaline sulphide, with a little excess of sulphur, but quite free from sulphate, dissolves: hence the oxygen of the alkaline oxide, converted into sulphide, must combine wholly with iron, and not in any degree with sulphur, so that oxide of iron should exist in the product of this fusion. When the foregoing mixture is melted in contact with carbon, the result is different, and metallic iron is separated, which, at a sufficiently high temperature, fuses into a lump easily detached from the slag.[1] Berthier has recorded the following experiment:—

Protosulphide of iron, 1 equiv.	=	10·80 grms.
Carbonate of soda, 1 equiv.	=	13·32 ,,

[8] Tr. 1. p. 399.

[9] Gris métalloïde. It may be translated *metalloidal grey*, indicating that it is somewhat less in degree than *metallic* properly so called.

[1] Berthier, Tr. 2. p. 192.

The mixture, heated in a brasqued crucible to 150° (Wedgwood's pyrometer), yielded a button of white crystalline cast-iron, which flattened sensibly under the hammer before breaking, and weighed 5·3 grms., or more than $\frac{4}{5}$ of the iron contained in the sulphide. The slag was lamellar, black, feebly metallic in lustre, with a slight bronzy tint; it had partially infiltrated into the brasque.

Protosulphide of iron heated in admixture with charcoal and baryta or lime.—Protosulphide of iron is in great measure reduced when heated in admixture with charcoal and baryta or lime; but as the double sulphide formed is very slightly fusible, the metallic iron remains disseminated through the mass in particles so minute as to be hardly visible.[2]

Protosulphide of iron heated with other metallic sulphides.—It combines in the *dry way* with various metallic sulphides, which are not volatile at high temperatures; and we have previously had examples of its occurrence in the different kinds of regulus produced in copper-smelting. It combines also in the *dry way* with the alkaline and earthy sulphides; but these compounds have as yet been most imperfectly studied. They are decomposable by water, which dissolves out the soluble sulphide and leaves the protosulphide of iron in a finely disintegrated state. They may be easily made either by heating in covered crucibles the mixed sulphides, or reducing mixtures of the respective sulphates with charcoal.

The two following experiments were made by Berthier[3]:—

1.	Protosulphide of iron	37
	Sulphide of barium	63

It melted at 150° (Wedgwood's pyrometer), was compact, homogeneous, dark metallic grey in colour, and even or crystalline in fracture.

2.	Protosulphide of iron	51
	Sulphide of calcium	49

It fused with difficulty at 150°, intumesced, and was metallic grey in colour with feeble lustre.

The following experiments have been made in my laboratory by Mr. Smith:—

Ratio of mixture.	Weights used in grains. Sulphide of lead.	Protosulphide of iron.
1. $2PbS + FeS$	5760	1060
2. $PbS + FeS$	5760	2120
3. $PbS + 2FeS$	5760	4240

1. The mixture was melted under charcoal, stirred with a piece of wood, and slowly cooled. The product consisted of two tolerably distinct layers: an upper one crystalline, and like galena in colour; and a lower one, more largely crystalline, rather darker in colour, and with less lustre.

2. The mixture was melted under borax. The product was a dark bluish-grey crystalline mass, which presented no sign of separation into

[2] Berthier, Tr. 2. p. 193. [3] Tr. 2. p. 192.

distinct layers. It was covered with a black slag, lined on its under surface with beautiful acicular crystals.

3. The product of fusion was a dark grey crystalline mass, which, like the last, appeared homogeneous throughout.

Protosulphide of iron heated with silica.—The following experiments have been made by Mr. Hochstätter in my laboratory. Of protosulphide of iron, containing 62·4% of iron, 600 grains in fine powder were intimately mixed by trituration with 1500 grains of fine white sand. The mixture was subjected during 2 hours, in a covered clay crucible, to a white heat. The product was a fritted mass, consisting apparently of the unchanged sulphide and silica. A portion of the mass was digested with hydrochloric acid until everything soluble was extracted; sulphuretted hydrogen was copiously evolved, and the sulphide of iron dissolved was found to contain 61·33% of iron. The residual silica contained 4·7% of the total iron of the original sulphide, which iron was extracted after fusion with bisulphate of potash. The result of this experiment would lead to the conclusion that silica does not act in a sensible degree upon protosulphide of iron at a high temperature.

Protosulphide of iron heated with silica and carbon.—The following experiments have been made by Mr. Hochstätter in my laboratory:—Of protosulphide of iron, containing 60·63% of iron, 600 grains in fine powder were intimately mixed by trituration with 600 grains of fine white sand, and 300 of charcoal-powder. The mixture was heated to whiteness, during 2 hours, in a covered plumbago crucible. The product was a slightly coherent mass, in which large and small metallic globules were diffused. These globules were removed by the magnet, freed as far as practicable from adherent sand and charcoal, and then fused, with the addition of a little alumina, in a covered crucible. Two buttons were thus obtained, which were hard and brittle; the fracture was light-grey, largely crystalline, yet dull in lustre, owing to the cleavage planes being finely granular in structure. The fine powder was only feebly acted on by digestion with hydrochloric acid, a little sulphuretted hydrogen being evolved. A large amount of insoluble matter remained even after long boiling with hydrochloric or nitro-hydrochloric acid. In the analysis of this product, its fine powder was fused, in a platinum crucible, with a mixture of 1 part of chlorate of potass, and 4 of the mixed carbonates of potash and soda.

Two other experiments, similar to the foregoing, were made, and the results are stated in the following table. The specific gravity of the button obtained in the last was 6·88:—

No. of experiments.	Weight in grains of materials taken.			Composition of the button per cent.			Loss on 100 parts of sulphur.
	Sulphide of Iron.	Silica.	Charcoal.	Iron by loss.	Silicon.	Sulphur.	
I.	600	600	300	80·23	18·77	1·00	97·46
II.	1500[4]	1500	800	83·28	15·32	1·40	96·28
III.	2000[4]	2000	1100	81·53	16·76	1·71	92·82

[4] The sulphide of iron contained 62·4% of iron.

From the results of the foregoing experiments, it appears that protosulphide of iron is nearly completely decomposed at a high temperature by the joint action of silica and carbon. If in each experiment we assume that the residual sulphur exists in combination with iron, according to the formula $Fe^8S+6FeS$ (see p. 35), the composition of the first and third products may be nearly represented by the formula Fe^3Si, and that of the second by the formula Fe^4Si. The pertage composition calculated from these formulæ will be respectively as follow:—Fe 79·1%, Si 20·9%, and Fe 83·46%, Si 16·54%.

Protosulphide of iron heated with alkaline silicates or borates.—Berthier states that the alkaline silicates and borates, containing a certain proportion of acid, have no action on protosulphide of iron; but that the contrary occurs when they contain excess of base and carbon is present. In this case part of the alkaline base, in accordance with the reaction previously considered, decomposes part of the sulphide of iron, and in amount, *cæteris paribus*, proportionate to the elevation of temperature. The same may also be stated of basic silicate of lime, whether free or in combination with basic silicate of alumina, as is the case in the slags generally produced in iron-smelting furnaces in this country, where coal or coke is used as fuel. One common variety, previously referred to, has the formula

$$Al^2O^3, SiO^3 + 2(3CaO, SiO^3).$$

Hydrochloric acid decomposes it, and there is always the disengagement of sulphuretted hydrogen. Moreover, I have observed in several analyses of this slag, which I have made, that the odour of sulphur was sensibly evolved on first heating the silica preparatory to weighing it.[6] This desulphurizing action of basic silicate of lime is of great practical importance with respect to the smelting of iron.

Protosulphide of iron heated with silicates or borates of manganese.—The silicates and borates of manganese appear, according to Berthier, to behave towards protosulphide of iron like the alkaline silicates and borates. Our knowledge of this subject is vague and unsatisfactory, and in place of facts we have scarcely more than conjectures. Mr. Parry, of the Ebbw Vale Iron-works, informs me that he has always found a considerable quantity of sulphur in blast-furnace slags which contained much manganese. Thus, in the slag produced in smelting spathic iron ore, the manganese, estimated as protoxide, amounted to 8%, and the sulphur to not less than 2%; whereas, with the same fuel, but with other ores not rich in manganese, the slag contained less sulphur, and the cast-iron a proportionately larger amount than in the first instance.

Sesquisulphide of iron. Fe^2S^3.—We are indebted to Berzelius for the following information respecting this sulphide. It is thrown down as a black precipitate by adding a solution of sulphate of sesquioxide of iron drop by drop into a solution of a hydrosulphate, but not on pouring the latter into the former, as in this case the sesquioxide of

[6] Vid. Metallurgy, First Part, p. 344.

iron would be reduced to protoxide with the precipitation of sulphur. It is decomposed by desiccation in the air. This sulphide is very slowly formed in the dry way by passing a current of sulphuretted hydrogen over sesquioxide of iron heated at the most to 100° C. The process is continued until water ceases to escape. If the temperature be too high, the iron decomposes the sulphuretted hydrogen, and bisulphide of iron is the product. The sesquisulphide may also be made by the same process at the ordinary temperature, by substituting very dry artificial hydrated for anhydrous sesquioxide of iron. If the hydrate be moist, decomposition proceeds very rapidly and without sensible rise of temperature; but the sulphide thus obtained passes very quickly in contact with air into a mixture of sesquioxide and sulphur, and can only be dried *in vacuo*. Once thoroughly dry, it suffers no change in the air. It is grey with a yellow tinge; but is neither so yellow nor bright as common iron-pyrites. It is not attracted by the magnet. At incipient redness, it parts with $\frac{1}{3}$ of its sulphur and is converted into magnetic pyrites. It partially dissolves in dilute sulphuric and hydrochloric acids, sulphuretted hydrogen being evolved, and an insoluble residue of bisulphide of iron left, which retains the form of the pieces operated on, but which, in the moist state, is so finely divided as to offer no resistance when spread with the finger over the skin: however, by washing and desiccation, it becomes solid and coherent. Sesquisulphide of iron is a sulphobase, and, as we have seen, is supposed to exist in copper-pyrites ($Cu^2S+Fe^2S^3$), and variegated copper ore ($3Cu^2S+Fe^2S^3$).[6]

Bisulphide of iron, or iron-pyrites. FeS^2.—It is found abundantly in nature, and of late years has become extremely valuable as a source of sulphur in the manufacture of sulphuric acid. It is dimorphous, crystallizing in the cubical and prismatic systems. Cubical iron-pyrites presents numerous and beautiful modifications which are highly prized by mineralogists; it has a bright metallic lustre and fine brass or golden yellow colour, which has caused it to be mistaken for gold; its specific gravity ranges from 4·9 to 5·1. The prismatic variety is termed white iron-pyrites, from its greyish or light greenish yellow colour; its specific gravity ranges from 4·65 to 4·9; it is not so widely diffused as the cubical; it is the usual concomitant of coal, and, unlike the cubical, is particularly liable to spontaneous decomposition in the air. Both varieties also occur massive and in different forms of aggregation, such as the botryoidal, reniform, etc. Both are brittle, extremely hard, giving sparks with steel, and non-magnetic. Their chemical reactions are the same, so that henceforward they will be considered under the general term of iron-pyrites. Bisulphide of iron may be formed by the following methods. An intimate mixture, prepared by triturating well together protosulphide of iron made in the dry way with half its weight of sulphur, is heated so that the excess of sulphur may be separated by distillation, and the temperature not rise quite to redness, when bisulphide of iron will be obtained

6 Berzelius, Tr. 2. p. 682.

as a bulky, deep-yellow pulverulent residue, metallic in appearance, not attractable by the magnet, and proof against the action of hydrochloric or hot dilute sulphuric acid. Sesquioxide of iron, anhydrous or hydrated, is heated in a current of sulphuretted hydrogen at a temperature exceeding 100° C., but below cherry-redness. At first water and sulphurous acid are formed, and as this gas is decomposed by sulphuretted hydrogen, the water which passes over is milky from the presence of sulphur. Hence a lower sulphide is generated, which is subsequently converted into bisulphide at the expense of the sulphur of the sulphuretted hydrogen, and with the liberation of an equivalent proportion of hydrogen. The process is completed when the produce ceases to increase in weight. If natural crystals of magnetic oxide, or sesquioxide of iron, anhydrous or hydrated, or of cárbonate of protoxide of iron, be employed, they are changed without losing their forms into bisulphide of iron, thus producing pseudomorphous crystals.[7] Wöhler obtained bisulphide of iron in small cubes and octahedrons by exposing an intimate mixture of sesquioxide of iron, sulphur, and chloride of ammonium to a temperature a little exceeding that at which this salt sublimes.[8] My friend, Mr. George Lowe, formerly of the Chartered Gas Company, has recorded the following interesting fact of the artificial formation of iron-pyrites in cubes and octahedrons. In subliming at a long continued and dull red-heat rough sal-ammoniac containing sulphate of ammonia in iron vessels coated internally with clay, the crystals were found upon this coating, which had become impregnated with chloride of iron.[9] Mr. Robert Weir Fox, of Falmouth, showed me very beautiful and perfect cubes of iron-pyrites, which, if I mistake not, were formed in a similar manner. In nature there can be no doubt that iron-pyrites, crystallized as well as massive, has frequently been produced in the *wet way;* and of this every mineralogical cabinet presents numerous and striking examples. It is often met with well crystallized in nodules of argillaceous iron ore, or impure carbonate of protoxide of iron in the coal-measures; and from this geological position it certainly cannot have resulted from even the most moderate igneous action. Moreover, there is positive evidence of its formation in liquids. Thus, the remains of a mouse, which had accidentally fallen into a solution of sulphate of protoxide of iron and had continued there a considerable time, were found covered with small crystals of iron-pyrites; and Bischof has recorded several recent instances of its production under similar conditions.[1] The aqueous solutions of alkaline and earthy sulphates, containing a salt of iron, are decomposed by the action of decaying organic matter, with the deposition of bisulphide of iron and disengagement of sulphuretted hydrogen.

When iron-pyrites is subjected to a red heat in a close vessel, sulphur sublimes, and the residue, according to Berzelius, consists of magnetic pyrites ($6FeS, FeS^2$); but at a strong red heat it is converted

[7] Berzelius, Tr. 2. p. 684.
[8] Berzelius, Jahresb. 17. p. 132.
[9] British Association Reports, 4th meeting, 1835, p. 582.
[1] Lehrbuch der Chem. u. Phys. Geologie, 1. p. 917 et seq.

to protosulphide, and in a current of hydrogen a lower temperature will suffice to produce this result, though sulphuretted hydrogen is formed only in very small quantity. The vaporization of sulphur appears, therefore, to take place less easily in its own vapour than in other gases.[2] For the same reason a current of steam promotes the liberation of carbonic acid from carbonate of lime heated in close vessels. Iron-pyrites is reduced to protosulphide when heated to redness in admixture with carbon, bisulphide of carbon being evolved. It is dissolved by nitric and nitro-hydrochloric acids, and by hot sulphuric acid with the separation of sulphur; but is not attacked by hydrochloric or dilute sulphuric acids.

Bisulphide of iron heated with protoxide of lead.—The following results are due to Berthier.[3] Native iron-pyrites and litharge were employed.

	Ratio of mixture in grammes.					
	1.	2.	3.	4.	5.	6.
Iron-pyrites	10	10	10	10	10	10
Litharge..................	60	125	200	300	400	500

These mixtures melted very easily, with the copious disengagement of sulphurous acid.

1. The product was a metallic button free from slag, which consisted of two parts: a lower one, which was most abundant, and was regarded as sub-sulphide of lead; and an upper one, similar in appearance to compact galena, but magnetic, which was composed essentially of sulphides of iron and lead, and probably contained a small quantity of these metals in the state of oxide.

2 and 3. The products were vitreous, opaque, black masses, staining the crucibles brown, and hard metallic lead (*plomb aigre*), granular in fracture and dark grey; in No. 2, the lead weighed 35 grms., and in No. 3, 40 grms.; in each case the lead was impregnated with a small quantity of slag, and contained from 0·8% to 1·0% of sulphur, together with a little iron.

Nos. 4, 5, and 6. The products were vitreous, transparent masses, fine resin red in colour, and buttons of lead, weighing respectively 45·4 grms., 54·8 grms., and 86 grms.

A larger proportion of litharge did not produce more than 86 grms. of lead; so desulphurization is complete when iron-pyrites is scorified with 50 times its weight of litharge.

Magnetic pyrites. 6 FeS, FeS^2, or 5 FeS, Fe^2S^3.—It is feebly attracted by the magnet, and is often itself magnetic: hence its name. It crystallizes in the rhombohedral system. It is brittle, has a metallic lustre, and a bronze-like colour. Its specific gravity is 4·6 or 4·7. In dissolving in acids it yields a residue of sulphur. It is readily fusible. It is met with pretty abundantly in nature, though rarely crystallized, and is not unfrequently nickeliferous. According to Berzelius, it is this compound which is usually produced artificially in the dry way. Thus it may be made by heating together without access of air an

[2] H. Rose, Pogg. Ann. 5. p. 533. [3] Tr. 1. p. 399.

intimate mixture of sesquioxide of iron or iron scale and sulphur, so long as sulphurous acid continues to escape; or by heating iron until it begins to burn with sparks and touching with a roll of sulphur, when the melted sulphide immediately drops and may be collected.

Supposed oxysulphide of iron.—Berzelius states, that when a mixture of sesquioxide of iron and sulphur is melted in a glass retort, at a temperature below redness, yet sufficient to drive off the sulphur in excess, sulphurous acid is disengaged, and a dark chestnut-brown powder remains. This powder is strongly attracted by the magnet, takes fire when gently heated, burns like tinder, and slowly dissolves in acids, producing a protosalt of iron without evolution of sulphuretted hydrogen. The same compound is also formed by heating in imperfectly closed vessels iron-pyrites (FeS^2) in coarse powder, so as to expel the sulphur; the calcined mass during cooling combines with oxygen, and retains very little tendency to dissolve in acids, with disengagement of sulphuretted hydrogen.[4]

Sulphate of protoxide of iron, copperas, or green vitriol. FeO, SO^3.—This salt is on several accounts specially interesting to the metallurgist, and is largely manufactured. Sulphate of protoxide of iron crystallizes with several proportions of water. The salt of common occurrence is in pale green transparent crystals belonging to the oblique prismatic system, and having the formula $FeO, SO^3+7\ HO$. At a gentle heat it melts in its water of crystallization; above 280° C. it loses 6 equivalents of water; at a higher temperature it becomes anhydrous, forming, provided air be excluded, a white gritty powder, which dissolves very slowly in water. Heated more strongly it is decomposed with the evolution of sulphurous acid and the production of sulphate of sesquioxide, as the following equation will explain:

$$2(FeO, SO^3) = Fe^2O^3, SO^3 + SO^2.$$

At a still higher temperature the whole of the sulphuric acid is expelled from this sulphate, partly as anhydrous acid and partly being resolved into sulphurous and oxygen, and there remains only sesquioxide of iron. Prior to this result it is stated that a basic sulphate of sesquioxide of iron is produced. The well known sulphuric acid of Nordhausen is distilled from this salt heated in earthen retorts after having been previously deprived of about 40% of its water of crystallization; the fumes which it emits are due to the anhydrous sulphuric acid contained in it. The acid is collected in stoneware receivers containing water. In Bohemia the distillatory apparatus is exactly similar in construction to the old *gallery furnace* for the distillation of cinnabar.[5] The manufacture of sulphuric acid by this process has long been carried on at various smelting works in Europe. When green vitriol is gently heated, with free access of air, stirring all the while, it is converted into Fe^2O^3, $2\ SO^3$. By gently heating a mixture of the dry salt

[4] Tr. 2. p. 689.

[5] Vid. Mémoire sur les fabriques d'acide sulfurique de Bohême. Par M. L. Ville. Ann. d. Mines, 4. sér. 1847, 12. p. 569.

and charcoal in a retort, sulphurous acid and carbonic acid are given off in the ratio of 78 volumes to 22, and the residue consists of sesquioxide of iron free from sulphide.[6] Green vitriol dissolves in 1·64 parts by weight of water at 10° C.—in 1·43 at 15°—in 0·87 at 24°—in 0·66 at 33°—in 0·44 at 46°—in 0·38 at 60°—in 0·37 at 84°—in 0·27 at 90°—and in 0·3 at 100°.[7] The aqueous solution is pale green, and reddens litmus; sulphuric acid precipitates the salt from it as a white crystalline powder of the formula FeO, SO^3+HO. When an aqueous solution of this or other salt of protoxide of iron is put into a close vessel, either with zinc or cadmium, metallic iron is slowly reduced.[8] In one experiment in my laboratory the reduced iron appeared on the surface of a strip of zinc in the form of small round masses, neutral sulphate of protoxide of iron being the salt used. Poumarède states that zinc at a somewhat increased temperature partially reduces salts of protoxide of iron, the iron being thrown down with its usual colour and of the specific gravity 7·84.[9] When the solution is exposed to the air, a yellow pellicle appears on the surface, oxygen is absorbed, with the formation of soluble sulphate and insoluble yellow disulphate of sesquioxide. Owing to the suspension of more or less of the latter, the solution is muddy, and has a yellowish brown colour; but, on standing, the basic sulphate subsides, leaving the supernatant liquor perfectly transparent and of a deep brown-red colour. The following equation will explain the reaction:

$$10(FeO, SO^3) + O^5 = 2Fe^2O^3, SO^3 + 3(Fe^2O^3, 3SO^3).$$

By exposure to the air at the ordinary temperature the crystals effloresce, becoming first white, and afterwards rusty brown on the surface, in consequence of the formation of a basic sulphate of sesquioxide of iron. This is especially the case when they have been deposited in a neutral solution, the presence of an excess of acid appearing to check, or at least to retard, oxidation. An aqueous solution of sulphate of protoxide of iron absorbs nitric oxide (NO^2), forming a dark greenish brown liquid in which the gas and the sulphuric acid are in the ratio of 1 to 4 equivalents. This remarkable compound may be procured in small brown crystals, of which the formula is $4\ FeO, SO^3 + NO^2$. The whole of the nitric oxide escapes *in vacuo*. It may also be expelled at a gentle heat, but not without undergoing slight decomposition, and producing an equivalent proportion of sesquioxide of iron. If the solution saturated with nitric oxide be exposed to the desiccating action of solid chloride of calcium under a glass receiver filled with nitric oxide, some sesquioxide of iron is generated at the expense of the oxygen of this gas.

Green vitriol is easily produced by dissolving metallic iron in dilute sulphuric acid, filtering the boiling solution, evaporating, and crystallizing. It is desirable that the solution should be acid. In

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[6] Gay-Lussac. Gmelin, Handb. 5. p. 238.

[7] Gmelin, Handb. 5. p. 240.

[8] Fischer, Das Verhältniss d. chemisch. Verwandschaft zur galvanischen Elektricität. Berlin, 1830, p. 141.

[9] L. u. K. Jahresb. 1847, p. 281.

some metallurgical works it is largely produced as an accessory product in making sulphuretted hydrogen by the action of dilute sulphuric acid on protosulphide of iron. It is formed by the spontaneous oxidation of a sulphide of iron in moist air, or by roasting a sulphide at a comparatively low temperature with free access of air. It not unfrequently occurs in the water from old coal-mines, and care should be taken not to employ such water in steam boilers, as it tends to corrode the iron with rapidity.[1] Its presence may be instantly recognized by the inky taste. The commercial salt is largely consumed in dyeing, and in the manufacture of colcothar. It may contain various impurities, such as manganese, zinc, copper, alumina, magnesia, lime, etc., and is often mixed with more or less of sulphate of sesquioxide of iron. It may be deprived of the latter by passing sulphuretted hydrogen through the solution, heating to expel the gas, and then separating the sulphur formed in the reduction of the sesquioxide, or by simply boiling with metallic iron. On the addition of sufficient alcohol it is thrown down as a greenish crystalline powder, which may be readily dried after washing with alcohol, and preserved without change in a stoppered bottle; it contains 7 equivalents of water as usual, and 20·143% of iron. We have been accustomed to use the salt thus prepared in standardizing solutions used for assaying of iron ores; and we have kept it for years without having found the least change in its composition. It is stated that green vitriol is sometimes contaminated with arsenious acid. Both arsenic and copper would be completely separated by metallic iron, and the process would be much accelerated by boiling. The commercial salt has frequently a grass-green colour, caused by the presence of a sulphate of sesquioxide.

Not fewer than four hydrates are stated to exist besides the common or hepta-hydrated variety, but of these I shall only refer to three. A salt with one equivalent of water is obtained by heating green vitriol to 140° C. *in vacuo*. The second with three equivalents of water is produced by evaporating at 80° C. a solution of green vitriol containing a considerable excess of sulphuric acid, until a white crust appears, which is the hydrate in question. The third with four equivalents of water is in chrysoprase-green coloured crystals by evaporating at 80° C. a solution of green vitriol free from an excess of sulphuric acid.

Double salts of the formulæ KO, SO^3+FeO, SO^3+6HO and $NH^4O, SO^3+FeO, SO^3+6HO$ have been described. They may be formed by the evaporation of an aqueous solution of green vitriol and sulphate of potash or ammonia respectively. They are nearly colourless, and have the same crystalline form as the analogous compounds of magnesia, oxide of zinc, and the protoxides of manganese, nickel, and cobalt.

Salts of the formulæ FeO, SO^2 (sulphite), FeO, S^2O^5 (hyposulphate or dithionate), FeO, S^2O^2 (hyposulphite or dithionite), FeO, S^4O^5 (tetrathionate), have also been described. The sulphite and dithionite are formed in equal equivalents by the action of sulphurous acid dissolved in water upon iron filings.[2]

[1] Riley. [2] Berzelius, Tr. 3, p. 572.

Neutral tersulphate, or sulphate of sesquioxide of iron. $Fe^2O^3, 3SO^3$.—Ulrich has described the anhydrous salt. It was observed at the sulphuric acid works at Oker, in the Harz, on pouring out the concentrated acid from the platinum stills, in the state of glittering particles, which subsided on leaving the acid at rest. The deposit consisted of minute pale peach-coloured crystals in truncated rhombic octahedrons. The largest did not exceed 0^m001 in diameter. The salt was nearly insoluble in water; nor did it dissolve to a much greater extent in hydrochloric acid. It was instantly decomposed by ammonia, with the separation of hydrated sesquioxide of iron. On keeping it was changed into a tender yellow powder, from the absorption of water, from which it had not been protected.[3] It occurs near Copiapó, in Coquimbo, forming a bed in a felspathic rock, and near Calama, in Bolivia. It is massive or crystallized in the rhombohedral system, and has the formula $Fe^2O^3, 3SO^3+9HO$. It may be made by boiling 2 equivalents of sulphate of protoxide of iron with 1 of sulphuric acid, and adding nitric acid in small quantities until it ceases to produce an evolution of gas. It may also be directly prepared by mixing strong sulphuric acid and sesquioxide of iron and stirring them well together; much heat is evolved, and on further raising the temperature slightly the excess of acid is expelled. It dissolves in water, forming a red solution which on evaporation yields a pale yellow deliquescent residue. In this state, according to Berzelius, it usually contains an excess of acid, owing to incomplete saturation with the oxide of iron in the first instance. On gently heating the residue not quite to redness the free acid is driven off, and the neutral salt is left in the state of white powder, which dissolves very slowly in water. The solution reddens litmus, is orange coloured, and by evaporation is converted into a reddish-yellow syrup which dissolves in alcohol. A dilute aqueous solution does, and a concentrated one does not, become turbid on boiling. The more dilute, the greater the turbidity and the lower the temperature required to produce it: tribasic sulphate is thrown down. The salt is insoluble in strong sulphuric acid. It is changed by the action of sulphuretted hydrogen into sulphate of protoxide with liberation of sulphuric acid and the deposition of sulphur. By digestion of its solution with iron filings hydrogen is evolved, with the formation of sulphate of protoxide of iron and the precipitation of a basic sulphate of sesquioxide. It is better adapted than any other salt for the preparation of anhydrous sulphuric acid by dry distillation. A solution of this salt, cold as well as hot, particularly when free acid is present, dissolves most of the metals, yielding oxygen to them and being reduced to sulphate of protoxide: sulphates of the metals are formed. Silver and all other metals exceeding it in affinity for oxygen are dissolved in this menstruum.[4] It is stated that a solution of neutral sulphate of sesquioxide of iron decomposes chloride of sodium at 60° C. with the

[3] Berg. u. hüttenm. Zeit. 18, p. 219. 1859.

[4] I have freely used Berzelius's description of this salt. Vid. Tr. 3. p. 583.

separation of hydrochloric acid; and that, when a mixture of the dry salt and chloride of sodium is sufficiently heated with access of air, chlorine is evolved and sulphate of soda and sesquioxide of iron are left.

Sulphates of sesquioxide of iron having the following formulæ have been described:

(1.) Fe^2O^3, $2SO^3$, or $2(Fe^2O^3, 3SO^3) + Fe^2O^3$. Bisulphate of sesquioxide of iron (Gmelin).

(2.) $2Fe^2O^3$, $3SO^3$, or Fe^2O^3, $3SO^3 + Fe^2O^3$, sesquisulphate of sesquioxide of iron. This formula, with the addition of 8HO, is assigned to the mineral from Chili which Prideaux designated *fibro-ferrite*, and which he was the first to analyse.[5] It consists of delicate silky fibres parallel to each other. It has a pale greenish-yellow colour, and is a very pretty mineral.

(3.) Fe^2O^3, SO^3, or Fe^2O^3, $3SO^3 + 2Fe^2O^3$. Monosulphate of sesquioxide of iron (Gmelin), and biferric sulphate (Berzelius). It is stated to contain 3 equivalents of water. According to Soubeiran, it is deposited as a light yellowish-red powder by heating an aqueous solution of neutral sulphate of sesquioxide (Fe^2O^3, $3SO^3$) to which carbonate of potash has been added so long as the precipitate produced ceases to be re-dissolved.

(4.) $2Fe^2O^3$, SO^3, or Fe^2O^3, $3SO^3 + 5Fe^2O^3$. Bibasic or disulphate of sesquioxide of iron (Gmelin), and quintiferric sulphate (Berzelius). According to Berzelius, this is the rust-coloured deposit formed when an aqueous solution of green vitriol is left exposed to the air; but Wittstein states that this is an error, and that the salt forming by the action of the air on a solution of green vitriol has the formula $2Fe^2O^3$, $3SO^3$ + 8HO.[6] The true salt is deposited as a red, flocculent, and somewhat gelatinous substance by incompletely precipitating a solution of neutral sulphate of sesquioxide with ammonia. When hydrated it contains 6 equivalents of water.

(5.) $3Fe^2O^3$, SO^3, or Fe^2O^3, $3SO^3 + 8Fe^2O^3$. Terbasic or trisulphate of sesquioxide of iron (Gmelin), and octaferric sulphate (Berzelius). It is deposited by boiling a dilute aqueous solution of neutral sulphate of sesquioxide (Fe^2O^3, $3SO^3$). It has a red colour, and resembles sesquioxide of iron; but on desiccation it acquires an ochre-yellow colour. Its formula is stated by Scheerer to be $2(3Fe^2O^3, SO^3)$ + 9HO.

(6.) $4Fe^2O^3$, SO^3, or Fe^2O^3, $3SO^3 + 11Fe^2O^3$. Quadrobasic sulphate of sesquioxide of iron (Gmelin). The existence of this salt, on the authority of Anthon, seems to need confirmation.

(7.) $6Fe^2O^3$, SO^3, or Fe^2O^3, $3SO^3 + 17Fe^2O^3$. Sexbasic sulphate of sesquioxide of iron (Gmelin). It is stated to be the product of the weathering of iron-pyrites in alum slate, and is described as dark brown, massive, fatty in lustre, yielding a brownish-yellow powder, insoluble in water, but slowly soluble in hot hydrochloric acid. Scheerer assigns for it the following formula: $2(7Fe^2O^3, SO^3)$ + 14HO.[7]

It will be remarked that the equivalents of base in excess of that required to form Fe^2O^3, $3SO^3$ increase in the following ratios from No. 3 inclusive: 2, 5, 8, 11, 17; 14 being absent.

Salts of the following formulæ are described, but for information concerning them the reader is referred to Berzelius:

FeO, $SO^3 + Fe^2O^3$, $3SO^3$. It is produced when green vitriol is ex-

[5] Phil. Mag. 1841, 18. p. 397.
[6] Gmelin, 5. p. 242.
[7] Gmelin, Handb. 5. p. 241.

posed to the air until the ochreous basic sulphate of sesquioxide of iron ceases to be formed.

$3FeO, SO^3+2(Fe^2O^3, 3SO^3)+4HO$. This salt was discovered by Abich. It crystallizes in the cubical system. Although this compound has no special reference to the metallurgy of iron, yet it has points of interest which induce me to describe its mode of preparation. Of crystals of green vitriol 16 parts by weight are dissolved in water so as to form a concentrated solution: this is mixed with its own weight of strong sulphuric acid, and heated to the boiling point; 1 part of common nitric acid and a concentrated solution containing 5 or 6 parts of alum are added, after which the whole is evaporated in a water-bath at a temperature not exceeding 70° C. During evaporation a dark-brown crystalline powder is deposited, which, after well draining off the mother-liquor, is dissolved in water strongly acidulated with sulphuric acid. This solution is slowly evaporated, when partly at the bottom and partly at the surface dark coloured crystals are formed which collect into a crust and gradually fall to the bottom. The crystals are a combination of the cube and octahedron. To free them from water they are washed with very strong alcohol and afterwards rapidly dried. Their colour is dark green, approaching black. Their facets have nearly the lustre of diamond. They may be preserved in dry air in a well-stoppered bottle. Abich states that this salt is not produced unless a small quantity of the sesquioxide of iron is replaced by alumina. If the evaporation of the acid solution takes place too quickly, the salt separates in crystalline scales with a less proportion of water; but, what is singular, this may be prevented by the addition of sulphate of copper to the extent of $\frac{1}{16}$ of the weight of the green vitriol employed, though no copper enters into the crystals of the salt. Barreswill obtained this salt of a deep-blue colour by the following process:—A saturated solution of green vitriol is divided into $\frac{1}{3}$ and $\frac{2}{3}$ by measure. The former is boiled with sulphuric acid and nitric acid so as to change it into sulphate of sesquioxide of iron, and is afterwards mixed with the $\frac{2}{3}$ of the original solution. To this mixture strong sulphuric acid is added in small quantities, and at intervals sufficient to prevent any sensible rise of temperature until the whole of the salt of iron has been precipitated. The precipitate has almost the colour of Prussian blue, and may be freed from moisture on a dry brick. In this state it does not dissolve in pure water without losing its blue colour.[8]

$FeO, SO^3+6(Fe^2O^3, 3SO^3)+10HO$.

$Fe^2O^3, 3SO^2$. According to Berzelius, it is formed by dissolving hydrated sesquioxide of iron in sulphurous acid.

Berzelius has described a curious salt of the formula $3FeO, 2SO^3+3(Fe^2O^3, 2SO^3)+36HO$. It was found in large stalactites in the copper-mine at Fahlun. It occurs in red, transparent, small crystals, mixed with sulphate of magnesia: it is soluble in water.

There are also various double salts of much interest in a scientific

[8] Berzelius, Tr. 3. p. 589. 1851, p. 63.

point of view. I have devoted considerable space to the sulphates of iron, because a knowledge of them is desirable in reference to certain special departments of metallurgy to be considered hereafter.

Sulphides of Iron Roasted with access of Air.

The reactions are substantially the same in roasting every variety of sulphide; but there are two sulphides, namely, the protosulphide and the bisulphide, which require separate consideration.

Protosulphide.—Heated to dull redness it is rapidly oxidized with the evolution of sulphurous acid. The nature of the roasted product varies considerably with the temperature at which the process is conducted. At a low temperature much sulphate of protoxide of iron is formed, which at a higher temperature is resolved into sulphate of sesquioxide of iron (Fe^2O^3, SO^3) and sulphurous acid; and at a still higher temperature this salt loses the whole of its acid, leaving sesquioxide of iron as the final product. These reactions have been previously stated. Whether, supposing the temperature be gradually increased, the basic sulphate of sesquioxide Fe^2O^3, SO^3, derived from the sulphate of protoxide, loses only a portion of its acid and becomes more highly basic before its final and complete decomposition, seems probable; but, so far as my knowledge extends, the production of such a salt during the latter part of the process has not been established; notwithstanding, it has been announced as a fact, and the formula $3Fe^2O^3, SO^3$ assigned to it.[1]

Plattner has explained the mode in which he conceives the formation of sulphate of protoxide of iron to be effected; and, according to his views, *contact-action* plays an important part.[2] The production of sulphuric acid by this action in the roasting of disulphide of copper has already been fully described in the First Part of this work, and much of what was stated under that head is applicable to the case of sulphide of iron, and need not be here repeated. Sulphurous acid and protoxide of iron are supposed to be generated in the first instance. Immediately afterwards the acid by contact with the protoxide of iron and oxygen of the air is more or less completely converted into sulphuric acid, and the protoxide for the most part into magnetic oxide of iron. As the sulphuric acid forms, it exerts an oxidizing action upon the magnetic oxide and converts it into sesquioxide, with the liberation of sulphurous acid; while, at the same time, the portion of protoxide remaining unchanged combines with an equivalent proportion of sulphuric acid to form sulphate of protoxide of iron. Then follow the reactions whereby sulphate of sesquioxide of iron and finally sesquioxide of iron are produced. This theory may be very ingenious, but I am disposed to doubt whether it rests on satisfactory experimental evidence. It would appear that at the ordinary temperature, with the simple access of moist air, sulphide of iron is converted into sulphate of protoxide by the direct

[1] Grützner, Die Augustin'sche Silberextraction, 1851, p. 54.

[2] Die metall. Röstprozesse, p. 133.

oxidation of both its elements, the moisture present simply promoting oxidation, probably in the same way as in the rusting of metallic iron; and, if this be so, why, it may reasonably be asked, should not sulphate of protoxide of iron proceed from the direct oxidation of both elements of the sulphide in the ordinary process of roasting, heat in this instance being the agent in exciting and favouring the reaction? Assuming, as Plattner does, the distinct formation and isolated existence of protoxide of iron in the first stage, I have difficulty in understanding why sulphuric acid should not be produced *pari passu*, especially as this oxide is a powerful base. Assuming, on the other hand, that in the process of roasting, magnetic oxide, and not protoxide of iron, is the immediate result of the direct oxidation of the iron of sulphide of iron, the evolution of sulphur as sulphurous acid is intelligible. As soon as magnetic oxide of iron exists, Plattner's *contact-action* may come into play, and sulphate of protoxide of iron be then generated. There is no doubt of the fact that magnetic oxide of iron is always produced in greater or less quantity in all roasting operations in practice, whether on the large or the small scale.

Bisulphide of iron.—In roasting this sulphide there is direct combustion of a portion of the sulphur with the characteristic pale blue flame and the development of much heat. In other respects the reactions appear to be identical with those occurring in the case of protosulphide of iron, except that, under suitable conditions of temperature, bisulphide of iron may in an early stage of the process be changed more or less completely into magnetic sulphide.

Iron and Nitrogen.

It has been considered of late that nitrogen plays a very important part in the metallurgy of iron, and it is even maintained by some persons that it is an essential constituent of all ordinary kinds of steel. The demonstration of the presence of nitrogen in iron is by no means easy, and its quantitative determination in a satisfactory manner is a difficult problem. Hence, the results of different chemists who have investigated this subject are far from concordant; and I shall, therefore, present a detailed account of them. The effect of heating nitrogenous matters, such as leather parings, horn, ferrocyanide of potassium, etc., with iron, has long been known in the process of *case-hardening*; but it is only recently that the theory of the process has been elucidated by the aid of chemical analysis.

Berthollet found many years ago that when iron is strongly heated in a current of ammoniacal gas, it becomes brittle, without, as he believed, increasing in weight. Thénard[3] subsequently repeated Berthollet's experiment, and arrived at the conclusion that ammonia is resolved by contact with iron at a high temperature into nitrogen and hydrogen gases, and that, although the metal undergoes a remarkable change in its physical properties, its weight is only very slightly increased.

[3] Traité de Ch. 1834, 1. p. 434.

Savart[4] proved that iron thus treated increases $\frac{1}{650}$ in weight, and that its specific gravity was reduced from 7·78 to 7·66; and he attributed the increase to the combination of ammonia or one of its elements with the metal. Despretz[5] confirmed Savart's results as to the increase in weight and decrease in specific gravity: in five experiments the maximum increase was 11·538 and the minimum 5·046 for 100 parts of iron, the average being 7·798. These experiments generally lasted from 6 to 8 hours. Porcelain tubes were employed, and the temperature was that of redness. The iron is rendered white, brittle, and even friable, lighter, and less liable to change in the air or water than ordinary iron. It is attracted by the magnet, and dissolves readily in acids. Its specific gravity is occasionally reduced to 5. It was several times observed that the metal increased considerably in volume, though not in weight more than $\frac{1}{1000}$. When iron which had been thus exposed to the action of ammonia was heated to redness in a current of hydrogen, ammonia was evolved. When it was treated with sulphuric acid, the hydrogen liberated was found to be mixed with nitrogen, but less gas was produced than from an equal weight of pure iron, owing to the formation of ammonia, which was detected in large quantity in the solution. Despretz remarked that the carbonaceous residue obtained by the solvent action of the acid on iron which had been treated with ammonia, differed in appearance from that of ordinary iron, yet the amount of residue is stated to have been sensibly the same in each case.

In 1840 Schafhäutl published the results of quantitative determinations by himself of nitrogen in cast-iron. He employed Dumas' method of burning the iron *in vacuo*, and another exactly similar in principle to that of Will and Varrentrapp for nitrogenous organic substances, except that instead of soda-lime he used a mixture of caustic potash and caustic baryta.[6] In white cast-iron from Maesteg, South Wales, he found 0·76371 % of nitrogen; in grey cast-iron from Creuzot, France, 0·7202 %; in English cast-steel, 0·1831 %;[7] and in spiegeleisen, 1·20 %.[8]

In 1850 Marchand published the results of an investigation concerning the presence of nitrogen in iron. By the application of Lassaigne's test, nitrogen was detected in numerous varieties of cast-iron, and in still greater proportion in steel, but never in malleable iron. This test, which is stated to be extremely sensitive, consists in heating to redness in a glass-tube nitrogenous carbonaceous matter in admixture with potassium or sodium. Cyanide of the metal is formed, which is dissolved out by water; and to the solution a mixture of proto and sesquichloride of iron is first added, and then a little hydrochloric acid, when Prussian blue is precipitated. The iron tested by Marchand was in the state of fine powder. In the presence of iron ferrocyanide of potassium is formed.

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[4] Despretz, Ann. de Ch. et de Phys. 1829, 42. p. 122.
[5] Op cit.
[6] Phil. Mag 1840, 16. p. 44.
[7] Op. cit. pp. 517, 521, 585.
[8] Techn. Encyklopädie, Prechtl, 1847, 15. p. 364.

A mixture of carbon and pure iron, however intimate—such, for example, as is obtained by heating succinate or benzoate of sesquioxide of iron—gave no indication of cyanogen by Lassaigne's test. In operating upon the residue of oxalate of protoxide of iron, Marchand once obtained very faint traces of Prussian blue.

When cast-iron is heated with an excess of potassium the formation of cyanogen is completely prevented; and the same result occurs when the mixture is heated to redness with free access of air, the potassium in this case being too readily converted into potash.

When the residual iron in an experiment was tested a second time, after having been thoroughly washed and rapidly dried, Prussian blue was again formed; and as this substance continued to be produced by repeatedly operating upon the *same* specimen of iron, Marchand was led to suspect that the nitrogen might have been derived from atmospheric air rather than from the iron. He, therefore, proceeded to apply the test both in an atmosphere of hydrogen and of carbonic acid; and found that numerous specimens of cast-iron, which had previously furnished Prussian blue in sensible quantity, now produced a much less amount of it, and it was only after 5 or 6 days that a very feeble and often very doubtful indication of a blue precipitate appeared on the bottom of the glass vessel. However the experiments were modified with respect to the kind of iron or steel, the proportion of potassium, the degree of heat, the same negative result was always obtained.

In order to prove that the hydrogen or carbonic acid did not prevent the formation of cyanogen, Marchand heated animal charcoal with potassium in each of these gases, and found that cyanogen was copiously produced.

Marchand next ascertained that when Lassaigne's test is applied to cast-iron in an atmosphere of *nitrogen*, this gas is sensibly absorbed.

Marchand considered it desirable to repeat Schafhäutl's experiments, and subjected iron to the old method of analysing nitrogenous organic compounds, namely, by heating in admixture with protoxide of copper, when the nitrogen is evolved in a free state, and may be collected and measured. Every precaution appears to have been taken to ensure accuracy. In one determination 10 grms. (about 153 grains) were operated on, and found to contain 0·0189 % of nitrogen. In several combustions of cast-iron and steel with protoxide of copper, Marchand obtained the same result.

By the soda-lime process, which was conducted with every possible precaution, Marchand obtained the following results:—

No.	Nature of the iron.	Locality.	Nitrogen per cent.
1.	Cast-iron, grey	Rottleberode.........	0·009
2.	Do. another specimen ...	Do.	0·003
3.	Steel from a file	England	0·014

120 grms. of steel from the same file were dissolved in hydrochloric acid with the aid of heat; the residue, which weighed 0·287 grm., and consisted chiefly of earthy silicates in admixture with carbon, contained 0·00047 grm. of nitrogen.

In six other experiments with English, Swedish, and Mägdesprung cast-iron, Marchand obtained precisely the same results. The *possible* amount of nitrogen never exceeded 0·015 %.

It was ascertained that the presence of iron does not affect the accuracy of the soda-lime process by heating cast-iron in fine powder in admixture with a known weight of uric acid, when all the nitrogen in the latter was obtained.

Marchand concludes from his researches that the presence of nitrogen in cast-iron and steel cannot be admitted with absolute certainty,—that most probably it never reaches 0·02 %, and is generally considerably less,—that any nitrogen which may be present evidently belongs to enclosed foreign matters, which are no more to be regarded as essential constituents of the iron than enclosed slag,—and that when iron containing carbon is heated in admixture with potassium to redness with access of atmospheric air, nitrogen is absorbed with the formation of cyanogen.

Three different kinds of artificial graphite were submitted to Lassaigne's test, but not the smallest trace of cyanogen could be detected.

In 1852, Buff published the results of some experiments which he had made in Liebig's laboratory on nitrogenized iron.[a] He states that when iron wire was heated to redness in a current of ammoniacal gas, it became brittle, crystalline, and white, and increased 6 % in weight; its specific gravity was reduced by this treatment from 7·416 to 7·145; on burning it with soda-lime ammonia was formed. By heating sesquichloride of iron to redness in ammoniacal gas, he procured scales of tough metallic iron, which contained 0·043 % of nitrogen. Iron, which he reduced from sesquioxide in a current of ammoniacal gas, contained 0·079 % of nitrogen. He found that when iron containing 1·8 % of carbon was heated to redness in a current of ammoniacal gas, it lost its deep black colour, became grey-white, and contained 1·159 % of nitrogen; the iron, upon which he operated in this experiment, was prepared by reducing sesquioxide of iron in a current of carbonic oxide. In a specimen of cast-iron smelted from bog iron-ore, he found 0·26 % of nitrogen.

Fremy has confirmed the accuracy of Despretz's results with regard to the action of ammonia on iron at a red heat, and shown that nitrogen, and not an amidogen compound, combines with the iron; for, when the nitrogenized iron is heated to redness in a tube in a current of oxygen, the metal is wholly converted into sesquioxide of iron, nitrogen is disengaged, but not the smallest trace of water is formed.[1]

The action of pure and dry nitrogen upon iron has been examined by Fremy, and he finds that while "it only combines with great difficulty with iron prepared by the ordinary processes of manufacture, it may combine with the metal when the latter is in a nascent state."

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[a] Ann. d. Pharm. u. Chem. 1852, new series, 7. p. 375. [1] Comp. Rend. 1861, 52. p. 322.

He thus obtained nitrogenized iron by passing nitrogen over oxide of iron at the moment of its reduction, whether by hydrogen or carbon.

In order to nitrogenize nearly completely small bits of iron wire by ammonia, Fremy often found it necessary to pass a current of the gas over the metal heated to redness during three entire days. This led him to seek for a more rapid method, and he states that he has completely attained his object by exposing anhydrous protochloride of iron to the action of a current of dry ammoniacal gas at a bright red heat. He states that chloride of ammonium is disengaged, and "a very curious amidogen salt, which immediately decomposes water with the production of water and oxide of iron." About 200 grs. (3086 grains) of protochloride of iron are thus treated at a time in a porcelain tube. This method of preparation had been long previously described by Buff.[2] After the operation, the metallic product will occur in the state of an intumesced partially melted mass; it is sometimes grey, but often metallic, white, and brilliant; it is identical with the nitrogenized iron produced by Despretz's process; it may easily be reduced to powder; it is less oxidizable than pure iron; it is very slowly attacked by nitric acid, but, on the contrary, rapidly by sulphuric and hydrochloric acids; on solution in acids, salts of iron and ammonia are formed; it is not decomposed at a red heat, and oxygen only attacks it at a high temperature, changing it into sesquioxide of iron; it is immediately decomposed by exposure to a gentle heat in a current of dry hydrogen with the formation of ammonia and a residue of pure iron; it is easily magnetized, and, like steel, permanently retains magnetism, but it appears to possess this property in a less degree than common steel. When nitrogenized iron is heated in a charcoal brasque, it is converted into a metallic mass which resembles steel, and, like it, acquires great hardness in the usual process of tempering. Fremy remarks that, if nitrogen still exists in the metal after having been thus treated, it is no longer in the same state as in simple nitrogenized iron; for, when it is heated in a current of hydrogen, no trace of ammonia is evolved.

According to Fremy the proportion of nitrogen in simple nitrogenized iron may be easily determined by the loss which the metal undergoes when heated to redness in a current of dry hydrogen; and in this manner he found that the substance produced by heating protochloride of iron in nitrogen contained 9·3 % of nitrogen. This corresponds to the formula Fe^5N, but this may not be correct, for, as Fremy remarks, it is not certain that the compound thus obtained is in a state of absolute purity: the temperature at which it is formed and the atmosphere of hydrogen which surrounds it at the moment may cause its composition to vary.

Fremy found 9·8 % of nitrogen in a specimen of nitrogenized iron, which he prepared by exposing a small cylindrical piece of very pure iron to the action of ammonia at a red heat during 20 hours.

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[2] Ann. der Chem. u. Pharm. 1852, 83. p. 375.

Fremy examined English, French, and German steel of well known "makes" and of high repute in commerce, and detected nitrogen in them all, as was shown by the evolution of ammonia which occurred when dry hydrogen was passed over fine filings of the metal heated to redness in a porcelain tube.

Several years ago the action of ammonia at a high temperature upon iron was examined in the metallurgical laboratory by Mr. Dick. Porcelain tubes were used containing thin iron wire in the form of a helix. In one experiment, which was only continued 1¼ hour, the helix increased in weight from 254·17 grs. to 255·30 grs. A piece of straight thick iron wire was operated on at the same time, and increased in weight from 302·03 grs. to 302·60 grs.; its surface was white; it was only superficially changed, and on bending it the altered portion scaled off: the scales were attracted by the magnet. The helix was white and remarkably brittle, and the fracture very brilliant. A piece of the helix was dissolved in hydrochloric acid, care being taken to exclude air; ammonia was distinctly evolved from the solution by the addition of excess of potash. A comparative experiment was made with unaltered iron wire of the same kind as that of which the helix consisted, but not a trace of ammonia was detected.

M. Bouis, by the direction of General Morin, sought for the presence of nitrogen in malleable iron, steel, and cast-iron, and in every instance succeeded in finding it.[3] He employed the process of passing dry hydrogen over the metal heated to redness. The gas after desiccation passed over a long column of pumice stone heated to redness, and afterwards through a succession of several cylindrical glasses filled with fused chloride of calcium. In every experiment two porcelain tubes were placed in the furnace side by side, and through both currents of the same dry hydrogen were passed. To each was attached a Will's tube containing very dilute sulphuric acid of known strength as determined by the method of standard solution. The metal to be tested was put into one of the tubes, the other remaining empty, and serving as a check. Bouis states that whenever iron or steel was heated in hydrogen white vapour appeared and traversed the acid solutions without condensing; it had a strong odour of burnt organic matter different from that of burning horn, and only lasted during a few moments. The hydrogen merely removed the nitrogen rapidly from the surface of the metal; for when bars of steel, which had been subjected to the action of hydrogen during a whole day, were filed and again operated upon, as much nitrogen was evolved in the state of ammonia as in the first experiment. Hence Bouis remarks that the quantitative estimation of nitrogen cannot be made by this process, unless the metal is in a state of very fine division or the process is continued during a very long time.[4] The following are Bouis' results:—

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[3] Comp. Rend. 1861, 52. p. 1195. [4] Ibid., p. 1249.

Nature of the metal.	Percentage of nitrogen.	Remarks.
Krupp's steel (spirale d'acier).....	0·085	Hydrogen badly purified and badly dried.
Do. do.	0·011	Very thin, washed with ether before trial.
Cast-steel in blades..................	0·059	Surface presented 380 cub. centim.
Do. do.	0·037	Numerous blisters (beaucoup de boursoufflures).
The last after filing	0·031	
Jackson's cast steel..................	0·058	In very fine shavings by a planing-machine.
Wootz	0·12	In very fine and very thin shavings.
Wrought iron (fer doux) in blades	0·18	Surface presented 200 cub. centim.
Card wire..............................	0·14	350 metres in length.
White cast-iron in small fragments	0·15	Very hard and manganesiferous.
Grey do. fragments	0·00	

Bouis states that he found very small quantities of nitrogen in the residues obtained by the action of acids or iodine from Jackson's and Krupp's steel, and from Wootz.

Boussingault has estimated the proportion of nitrogen in different kinds of iron by two methods. In the first, the determination is made by volume, just as in the original nitrogen analysis of organic compounds. The metal in wire or shavings is placed in the middle of a glass combustion tube surrounded with copper foil, of which one end communicates with a carbonic acid gas generator, while the other is connected with a delivery tube proceeding to a mercurial trough. The metal is mixed with cinnabar which extends beyond towards the carbonic acid generator. Atmospheric air is completely expelled from the combustion tube by a current of carbonic acid, which is then stopped and the delivery tube put in communication with an inverted receiver containing solution of caustic potash. The metal is now heated and the whole of the cinnabar is gradually passed over it in the state of vapour. When the operation is finished and the combustion tube has cooled down much below redness, a current of dry carbonic acid is sent through in order to drive the remaining nitrogen into the mercurial receiver.

By this method nitrogenized iron prepared by Despretz's process was found to contain 2·66 % of nitrogen, a specimen of cast steel 0·057 %, a wire of malleable iron 0·124 %, and another specimen of similar wire 0·068 %.

In the second method, Boussingault estimated the nitrogen as ammonia.[5] The iron is dissolved in hydrochloric or dilute sulphuric acid, and the solution is boiled with the addition of excess of potash or lime in a large flask connected with a suitable condensing apparatus. The distillate in successive portions of 50 cub. centim. is tested for ammonia. It is essential that the potash should be absolutely free from nitrate or nitrite; for, otherwise, some ammonia is always produced by the action of the protoxide of iron thrown down. From the difficulty of obtaining potash sufficiently free from these impurities lime is preferred. The ammonia which passes over in the

[5] Comp. Rend. 1861, 53. p. 77.

distillate is estimated by a standard solution of sulphuric acid. When this process is properly conducted, it would appear that in some cases the whole of the nitrogen is evolved in the form of ammonia. The following are some of Boussingault's results :—

		Percentage of nitrogen.
Iron nitrogenized by Despretz's method gave by wet method (just described)		2·655
Do. do. do.	cinnabar method	2·660
Cast steel	wet way	0·042
Do.	cinnabar method	0·057
Pure iron prepared by Péligot	wet way	none.
Wrought iron wire	do.	0·0075
Piano wire (corde de Berlin)	do.	0·0070
Do.	do.	0·0086
Krupp's steel	do.	0·022

From the experimental evidence which has now been advanced we may conclude, 1st. That nitrogen does combine with iron. 2dly. That its presence has been detected in malleable iron, cast-iron and steel. 3dly. That when present in sensible proportion in iron it modifies certain of the physical properties of the metal in a remarkable manner.

Nitrate of protoxide of iron. FeO,NO^5.—It is prepared by dissolving sulphide of iron in dilute cold nitric acid. Towards the end of the operation, in order completely to saturate the acid, the liquor may even be gently heated. Sulphuretted hydrogen is disengaged, so that the iron is oxidized at the expense of water. A greenish blue solution is thus obtained, which by evaporation *in vacuo* yields pale green crystals very soluble in water. In the presence of an excess of acid, the solution is easily decomposed by heat; but a solution of the neutral salt is only decomposed at about 100° C., when nitric oxide (NO^2) is disengaged, and a subnitrate of sesquioxide is copiously deposited.[6] If metallic iron be substituted for sulphide of iron, ammonia is produced.

The action of nitric acid upon iron varies much with the specific gravity of the former.[7] The metal dissolves in acid of sp. gr. 1·034 without any evolution of gas, nitrate of protoxide of iron and nitrate of ammonia being formed, as is explained by the following equation :—

$$10NO^5 + 8Fe + 3HO = 8(FeO, NO^5) + NH^3, NO^5.$$

Nitric acid of sp. gr. 1·073 dissolves iron slowly, but not without sensible disengagement of gas; and the solution contains nitrate of sesquioxide as well as protoxide of iron, and nitrate of ammonia. Acid of sp. gr. 1·115 in dissolving iron produces only nitrate of sesquioxide without any ammonia, so that this alkali only appears when nitrate of protoxide of iron is formed. By the action of acid of higher specific gravity than 1·115 nitrate of sesquioxide of iron is always

[6] Berzelius, Tr. 3, p. 573.

[7] An interesting paper, entitled "Recherches sur les Azotates de Fer," has been published by Scheurer-Kestner, and from this I have taken nearly the whole of the following information on the nitrates of the sesquioxide of iron. Ann. de Chim. et de Phys. 3. s. 55. pp. 330-342. 1859.

exclusively generated. But the nature of this nitrate varies according to certain special conditions. Thus, on leaving the acid to act during some time upon the metal, more or less basic salts are produced, which gelatinize in the liquid and dissolve by digestion in water at 40° C. in the course of 24 hours. In order to prevent the formation of basic salts, which renders the preparation of the neutral salt difficult, the iron should be taken out of the acid as soon as the reaction begins to moderate itself.

Nitrate of sesquioxide of iron. $Fe^2O^3,3NO^5$.—By the action of nitric acid of sp. gr. 1·332 upon a suitable quantity of iron, a solution of sp. gr. 1·580 is obtained, which on cooling deposits the salt in fine rectangular prisms of a brown colour, owing to the interposition of mother-liquor. These crystals, when dried between bibulous paper, are nearly colourless. The proportions recommended to obtain the finest crystals are 4 equivalents of nitric acid of sp. gr. 1·332, and 2 of iron. The following equation explains the reaction:—

$$4NO^5 + 2Fe = Fe^2O^3, 3NO^5 + NO^2.$$

The action is very energetic, and solution is effected in about half an hour. On employing 3 kil. of acid of the above strength and 0^k 350 of iron, proportions in accordance with the equation, a slightly basic nitrate is produced, because some acid is evaporated by the heat evolved in the operation. But on employing 25 parts by weight of acid and 3½ of iron, a neutral solution is formed, which easily crystallizes. The crystals are very deliquescent, and dissolve in all proportions in water and alcohol, producing brown solutions, which are rendered colourless by the addition of nitric acid; after desiccation in a current of hydrogen, they had the following formula:—

$$Fe^2O^3, 3NO^5 + 18HO.$$

Considerable lowering of temperature is caused by the solution of the crystals. The salt is very readily decomposed by heat. At 50° C. vapour of nitric acid is evolved, and below a red-heat the whole of the acid is driven off, pure sesquioxide of iron remaining. The salt, when enclosed in a glass-tube hermetically sealed, undergoes no change at 100° C.; nor does it suffer any change by exposure to sunlight.[a] On boiling an aqueous solution of the salt, an insoluble basic salt is thrown down. All the nitrates of sesquioxide of iron, soluble or insoluble, are completely decomposed by boiling in water with carbonate of lime.

Nitrate of the formula $Fe^2O^3, 2NO^5$ (sesquibasic) may be prepared by dissolving the required proportion of hydrated sesquioxide of iron in a solution of the first described, or neutral salt. By cautious evaporation between 30° C. and 40° C., the solution of this salt becomes thick and syrupy, and afterwards converted into an amorphous shining black

[a] Scheurer-Kestner, Ann. de Chim. et de Phys. 3. s. 57, p. 231. 1859. Vide also a paper by the same author, entitled "Nouvelles Recherches sur l'Azotate Ferrique." Op. cit. 3, s. 65, p. 110. 1862.

mass. It dissolves in all proportions in water, but is insoluble in nitric acid, which throws it down as an ochreous deposit from its aqueous solution. By prolonged contact, nitric acid converts it into the neutral salt.

Nitrate of the formula Fe^2O^3, NO^5 (tribasic) may be formed in precisely the same manner as the last, which, moreover, it closely resembles in all respects.

By boiling the solutions of three nitrates of sesquioxide above described, the three following basic salts, it is stated, are respectively deposited:—

1. $2Fe^2O^3, NO^5 + HO$, or $Fe^2O^3, NO^5 + Fe^2O^3, HO$.
2. $3Fe^2O^3, NO^5 + 2HO$, or $Fe^2O^3, NO^5 + 2(Fe^2O^3, HO)$.
3. $4Fe^2O^3, NO^5 + 3HO$, or $Fe^2O^3, NO^5 + 3(Fe^2O^3, HO)$.

Wildenstein[9] and Hausmann[1] obtained crystals to which they assigned the formula $Fe^2O^3, 3NO^5+12HO$. The former states they were cubical, but the latter that they were prismatic; and this agrees with the statement of Scheurer-Kestner, and also with an observation of Vauquelin,[2] who, having left nitric acid in contact with iron scales during several months, obtained colourless crystals in the form of rectangular prisms. Wildenstein's cubes were as limpid as water, and had been very slowly deposited from a solution prepared by saturating slightly diluted nitric acid with iron, and evaporating to the specific gravity of about 1·5.

Scheurer-Kestner kept hermetically-sealed glass-tubes containing the sesqui- and tribasic nitrates of iron during a long time at 100° C.[3] After the lapse of a few hours the colour of these two basic salts was considerably changed, having passed from brown-red to brick-red. The solution appeared limpid by transmitted light, and turbid by reflected light. On opening the tubes no odour of nitric acid was perceived. Yet these basic salts had acquired new properties. A drop of sulphuric or hydrochloric acid, or of a solution of sulphate of potash or soda, occasioned a precipitate in them; whereas, before having been subjected to the action of heat, only strong nitric or hydrochloric acid produced a precipitate. After exposing the tribasic nitrate in the manner described to 100° C. during 72 hours, the liquid separated from the precipitate contained neutral nitrate ($Fe^2O^3, 3NO^5$). No further change occurred in an experiment prolonged during 144 hours. It is, then, only these two basic salts which are susceptible of decomposition under the conditions stated. The precipitate caused by sulphate of soda, dried first on unglazed porcelain and then in a current of dry air, was in the form of little black plates, insoluble in concentrated acids, but very soluble in pure water, reproducing a solution bright by reflected light and turbid by transmitted light. This solution no longer gave the characteristic reactions of the salts of iron on the addition of the ferrocyanides or sulphocyanides, but yielded precipitates with

[9] L. u. K. Jahresb. 1861, p. 306.
[1] Ibid., 1853, p. 371.
[2] Berzelius, Tr. 3. p. 592.
[3] Ann. de Chim. et de Phys. 3. s. 57, p. 231. 1859.

acids and sulphate of soda. The oxide thrown down had the formula Fe^2O^3, HO, and that obtained after heating during 144 hours had the same composition. The basic nitrates, then, are resolved by the action of heat into neutral nitrate and hydrated sesquioxide. These basic salts suffer change by long exposure to sun-light, the liquors separated becoming precipitable by sulphuric acid or sulphate of soda; but in the dark they undergo no change.

The description of the nitrates of iron must not be concluded without a few observations on the *passivity* of iron. This is a very curious and interesting subject, which may, possibly, be one day found to admit of valuable practical application. It has been investigated by several able observers, yet many of the phenomena are still unexplained. Iron dissolves very rapidly in nitric acid of sp. gr. 1·384; but when the liquor approaches saturation, the metal becomes bright, and, as it is termed, *passive*, *i. e.*, it is no longer acted on. It may be taken out and put into acid of lower specific gravity without causing any evolution of gas. On immersing it in the acid in contact with another piece of iron, it is instantly attacked as at first. If now removed and placed in the solution of nitrate of sesquioxide, it again becomes passive after a few instants. Scheurer-Kestner ascertained that the passivity of the iron did not depend on the greater or less degree of saturation of the acid. Schönbein states that iron made passive by fuming nitric acid continues so after exposure to the air during several hours, or even days; and Buff asserts it loses its passivity when all the acid is washed off. Iron wire, which is passive in cold nitric acid of sp. gr. 1·5, gives off gas somewhat below 80° C.[4]

IRON AND PHOSPHORUS.

These elements do not combine at the ordinary temperature; but when phosphorus comes in contact with red-hot iron, combination takes place with much increase of incandescence.

Phosphide of iron of the formula $Fe^{12}P$.—The product thus directly obtained has this formula; it is readily fusible, and, when melted, very liquid; it does not permeate the body of clay crucibles. I have prepared many pounds of it at a time by dropping bits of phosphorus on small pieces of thin sheet-iron or iron-wire, or on iron-filings heated to redness in a crucible, taking care to prevent access of air as completely as possible. This process, however, is very wasteful, as a large proportion of phosphorus escapes, with whatever care the manipulation may be conducted. I have not succeeded in thus introducing sensibly more than about 8 % of phosphorus into the iron. In one specimen made in considerable quantity, I found 8·23 % of phosphorus; and another prepared recently in my laboratory by Mr. Hochstätter with iron-wire contained 8·28 %. A portion of the latter was again treated in a similar manner with phosphorus, after which the total amount was only

[4] Gmelin, Handb. 1, pp. 355-362. All the facts published on the subject prior to 1848 are here collected.

8·405 %. It is possible that this compound consists only of iron containing in solution or suspension a phosphide with a larger percentage of phosphorus, such, for example, as Fe^4P. The fact of its having been obtained in distinct crystals is no certain proof of the contrary; for Professor Jósiah Cooke has shown that alloys of antimony and zinc of very variable composition have the same crystalline form.

A specimen resulting from direct combination in the manner described, and left to cool in the crucible, had the following characters: Its upper or flat surface was highly crystalline, presenting long, slender, interlacing prisms; and similar crystals were also visible round the sides. On breaking up the button, beautiful, brilliant, iridescent, prismatic crystals were found towards the central portion, which was cavernous. These crystals, as well as those round the sides, had for the most part a superficial blue colour, like that of watch-springs.[a] The fracture was very uneven, and confusedly crystalline; when freshly made, its colour was greyish white, but it soon acquires a somewhat variegated tarnish, of which the prevailing tint is reddish grey. This phosphide is easily pulverizable. It is very hard, being only just scratched by felspar, but not at all by apatite. The specific gravity of a piece of the mass was 7·245. It is strongly attracted by the magnet. Its composition may be represented by the formula $Fe^{18}P$. It is only partially soluble in hydrochloric acid, cold or hot, with the evolution of hydrogen, an insoluble black powder remaining. This residue is in an extremely fine state of division; it subsides very slowly, and passes readily through the filter. On diluting with water the hot concentrated acid liquor containing the residue in suspension, the odour of phosphuretted hydrogen was distinctly perceived; but on diluting the same liquor when cold, the odour of this gas could not be detected. After subsidence and thoroughly washing with alcohol, the residue when dry was dark brown. Heated before the blowpipe, it emitted a bluish light and the odour of phosphorus, and melted globules of phosphorized iron were obtained. The phosphide was completely decomposed by digestion in hot sulphuric acid, sulphurous acid being evolved, and a micaceous white precipitate of sulphate of sesquioxide of iron formed. It dissolves only partially in dilute sulphuric acid, with the formation of a residue similar to that resulting from the action of hydrochloric acid. The phosphide is slowly, yet perfectly, dissolved by digestion either in strong nitric or nitro-

[a] I submitted some of these crystals to Professor Miller, of Cambridge, who has favoured me with the following results of his examination of them:—"They belong to the pyramidal system, and present undoubted cleavages parallel to the faces of the form I O O [of his system]. The crystals are square prisms, having remarkably bright and even faces, without a trace of end faces of any kind. These prisms are for the most part attached at both ends to the crystalline mass of phosphide. When broken out the broken ends exhibit a very bad cleavage much interrupted by conchoidal fracture. The surface is gold yellow, and the fractured surface more nearly tin-white. One of the square prisms which I detached had the two sides which were exposed of a gold yellow colour. The other two sides were tin-white. I therefore conclude that these sides were obtained by cleavage. The reflection from them was not so good as from the exposed faces, but very much better than from the end cleavage."

hydrochloric acid. It dissolves also in dilute nitric acid with the aid of heat. The phosphide is not acted upon by an aqueous solution of potash either cold or hot. By fusion with three times its weight of carbonate of soda at a red heat, a black product was obtained, which was magnetic, and evolved the odour of phosphuretted hydrogen on the addition of hydrochloric acid. By the action of a solution of chloride of copper on the phosphide during 8 days, and the separation of the precipitated metallic copper by dilute nitric acid, a crystalline powder was left, which contained 85·06 % of iron. This nearly corresponds to the formula Fe^6P.

Phosphide of iron of the formula Fe^8P.—It is prepared by heating the phosphide of the formula Fe^3P. [$Fe_{12}P$]

Phosphide of iron of the formula Fe^4P.—According to Berzelius, this phosphide is obtained by reducing at a high temperature (in a smith's fire) phosphate of protoxide of iron ($2FeO,PO^5$) mixed with a quarter of its weight of charcoal in powder. Care must be taken to have the phosphate in excess; for, otherwise, the carbon would expel a portion of phosphorus, and some cast-iron would be formed.[6] Half of the phosphorus is volatilized. Struve obtained this phosphide by strongly heating in a blast furnace, during 1½ hour, phosphate of sesquioxide of iron in a crucible brasqued with charcoal from sugar. Berthier states that this phosphide is formed by strongly heating (150° Wedgwood's pyrometer) in a brasqued crucible 1 part of sesquioxide of iron, with 2 or 3 parts of a mixture consisting of 0·5 of phosphate of lime, 0·25 of quartz, and 0·25 of glass of borax.[7] It is described as whiter than steel, bright, crystalline-granular, very hard and brittle, susceptible of a high polish, non-magnetic (or, according to Struve, only very feebly so), much more fusible than cast-iron, but a little less so than copper. Its specific gravity is stated to be 6·7. It is not acted upon either by hydrochloric or dilute sulphuric acid; and, according to Berzelius, it only dissolves with difficulty in strong nitric acid and in aqua-regia. This phosphide has been examined in my laboratory by Mr. Hochstätter. It was prepared by the process of Berzelius, substituting, however, phosphate of sesquioxide for phosphate of protoxide of iron. In every particular the statements of Berzelius have been found correct. But Struve's results are in some respects different: thus he states that it dissolves pretty readily in aqua-regia, and is also completely soluble in hydrochloric acid by long boiling, half of the phosphorus in this case passing as phosphoric acid into the solution; but what becomes of the other half, we are not informed. By roasting it is converted into basic phosphate of sesquioxide of iron. On the same authority it is affirmed that this phosphide of iron is always left when any phosphide of iron containing more phosphorus than it is subjected to a strong heat. It readily melts before the blowpipe, and retains its phosphorus for a very long time even in the oxidizing flame.[8] It is stated[9] that phosphide

[6] Berzelius, 2. p. 690.
[7] Tr. 2. p. 201.
[8] Berzelius, op. cit. p. 691.
[9] Gmelin, Handbook, 5. p. 222.

of iron of the formula Fe^4P may be formed by throwing bits of phosphorus on red-hot iron-filings. All that I can say is, that I have not yet succeeded in verifying this statement, though profuse in the expenditure of phosphorus; and that precisely the same results have been obtained at intervals of many years.

Diphosphide of iron. Fe^2P.—According to Schrötter, iron in a pulverulent state, like that obtained by reducing the sesquioxide by hydrogen, is converted with incandescence into phosphide of this formula by exposure to the vapour of phosphorus at a scarcely incipient red-heat.[1] It is described as grey, slightly sintered together, non-magnetic, attacked neither by hydrochloric nor nitric acid (?), and as burning when heated with the flame of phosphorus. Struve states that with the aid of heat, it slowly dissolves in hydrochloric and nitric acids, and that $\frac{4}{5}$ of the phosphorus pass as phosphoric acid into the solution; but iodine has no action upon it.[2] Exposed under borax to the melting point of cast-iron, it evolves phosphorus, leaving a well fused, dark iron grey, very brittle, non-magnetic mass, finely granular in fracture, of the specific gravity of 6·28, not attacked either by hydrochloric or nitric acid, and of which the composition may be represented by the formula Fe^6P. [3]

Phosphide of iron of the formula Fe^9P^8 (?)—Struve states that this compound is produced by exposing phosphate of sesquioxide of iron to a current of hydrogen at a white heat. It is described as an unfused mass, grey-white, metallic in lustre, and not attractable by the magnet. It undergoes no change in the air; it is readily attacked by nitric and nitro-hydrochloric acids, especially with the aid of heat, the whole of the phosphorus being converted into phosphoric acid; it is very slowly dissolved by hydrochloric acid, with the conversion of half of the phosphorus into phosphoric acid, and the other half into phosphuretted hydrogen which escapes.[4]

Phosphide of iron of the formula Fe^5P^2.—In the First Part of this work I described a pulverulent phosphide of iron of this formula. It was left by the action of dilute nitric acid on copper containing phosphorus and iron. But this observation requires confirmation.

Phosphide of iron of the formula Fe^3P^2.—According to H. Rose, it is very easily made by passing phosphuretted hydrogen over iron pyrites (FeS^2) heated to a degree insufficient to decompose the latter. Sulphuretted hydrogen is evolved, and the residue is the black, pulverulent phosphide, which is insoluble in hydrochloric acid, but soluble in nitric acid and aqua-regia. The following equation explains the reaction:—

$$3FeS^2 + 2PH^3 = Fe^3P^2 + 6HS.$$

It emits the flame of phosphorus before the blowpipe.[5]

[1] L. u. K. Jahresb. 1849, p. 246.
[2] Ibid., 1860, p. 77.
[3] Hvoslef, L. u. K. Jahresb. 1856, p. 284.
[4] L. u. K. Jahresb. 1860, p. 76.
[5] Berzelius, Jahresb. 13, p. 88; Tr. 2, p. 691.

The following is a list of all the phosphides of iron which I have met with :—

1. $Fe^{12}P$.	3. $Fe^{4}P$.	5. $Fe^{8}P^{3}$.	7. $Fe^{3}P^{2}$.
2. $Fe^{6}P$.	4. $Fe^{2}P$.	6. $Fe^{5}P^{2}$.	

Phosphorus, even in very small quantity, has a decided effect upon the malleability and strength of iron at ordinary temperatures, rendering it *cold-short*, i. e. brittle while cold. Although phosphorus may be present in sufficient proportion in iron to render it very cold-short, yet it may have no injurious effect upon the malleability of the metal at high temperatures such as those at which it is usually forged and rolled. There is no fact relating to the metallurgy of iron which seems to be better established than this, and certainly there is not one which is more generally received as correct. Karsten was of opinion, that so long as the phosphorus is below 0·5 %, there is little cause for apprehension respecting the quality of the iron; and that up to 0·3 % the only effect of phosphorus is to make iron harder without sensibly diminishing its tenacity. Iron not containing more than this proportion of phosphorus might be properly regarded as of the best and strongest quality. To the same metallurgist we also owe the following observations. Iron containing 0·6 % of phosphorus will not stand the breaking test, but stands the test of bending at right angles, and pretty well that of striking over the anvil; and with 0·66 % it does not under these tests manifest the qualities characteristic of cold-short iron properly so called. As soon as the proportion of phosphorus reaches 0·75 %, the decrease in tenacity is very notable, and the iron no longer completely stands the usual tests above referred to. With 0·8 % of phosphorus, iron is to be regarded as decidedly cold-short; and with 1 %, a bar can no longer be bent at right angles. According to Karsten all iron containing more than 1 % is extraordinarily brittle, and is only fit for very few applications.[6] Mr. Hochstätter prepared a button of iron containing 1 % of phosphorus, by melting fine iron wire cut into small pieces with a sufficient quantity of a phosphide of iron to yield the requisite amount of phosphorus. Under the hammer it flattened a little, and then broke across. Its fracture was for the most part largely crystalline, and presented very bright planes of cleavage, resembling those of antimony. It was harder and whiter in fracture than a button of melted iron free from phosphorus.

There are some interesting points connected with the discovery of phosphorus in iron. In 1781 Meyer published the results of an investigation concerning a " white earth " which he had discovered in cast-iron made from " bog iron-ores." He found that the solution of this iron in dilute sulphuric acid deposited a white precipitate, which is the earth in question. By heating this *per se* in a crucible made out of a solid piece of charcoal, he procured a " very beautiful button," hollow in the interior and containing prismatic metallic crystals. The metal was extremely brittle, easily pulverizable, very fusible, and not attracted by the magnet. He made

[6] Handb. d. Eisenhüttenkunde, Berlin, 1841, 1. p. 420, sec. 188.

numerous experiments upon it: he melted it with twice its weight of lead, and obtained a very uneven button, which could be hammered somewhat and cut; its fracture was granular; before the blowpipe it gave a semivitreous slag, and a metallic bead attractable by the magnet. Meyer concluded that it was a metal, or rather semi-metal, and that it caused the great fusibility of the cast-iron from bog iron-ore.[6] He published a second series of experiments on this supposed new metal, and proposed for it the name of Wassereisen or Hydrosiderum.[7] He gave a summary of its characters which leaves no doubt that it was phosphide of iron. Its specific gravity was 6·710. It was very slowly dissolved by the three mineral acids, but most rapidly (?) by oil of vitriol, and with this and hydrochloric acid it yielded crystals. In 1784 Meyer announced that his pretended new metal was only iron containing phosphoric acid; he begins his announcement with the confession that "to err in chemistry is, alas! too easy," and ends it with an expression of evident satisfaction that Bergmann had committed the same blunder.[8] In the collected works of this distinguished Swedish chemist, which appeared in 1783, is a chapter on the cause of the cold-shortness of iron, containing the following information:— A "white calx" was slowly deposited from the filtered solution of cast iron made from bog-iron ores in oil of vitriol. This "calx" heated with charcoal yielded a metal (or rather semi-metal, *regulus*, then termed) of the specific gravity 6·700; it was white, dull, and granular in fracture, with no sign of fibre, very brittle, easily fusible, and difficultly attacked by acids. He regarded it as a new metal, and called it Siderum. It is singular that the German and Swedish chemists should have been led at about the same time to the same conclusion as to the cause of cold-shortness in iron, and should both have proposed the same term, Siderum, for the supposed new metal.

In 1785, after the decease of Bergmann, his illustrious countryman, Scheele, published an excellent paper on the subject, which, like all the contributions to chemical science of this acute investigator, will ever be deserving of study.[9] He proved in the clearest manner that Siderum was only phosphide of iron. It is worthy of note that he precipitated the phosphoric acid as phosphate of mercury by the use of nitrate of mercury, so that in the application of the latter salt in the analysis of phosphates he forestalled H. Rose, who proposed only a few years ago a method for the quantitative estimation of phosphoric acid founded on the precipitation of phosphate of mercury by the nitrate of this metal.

In 1806 Vauquelin communicated to the French Institute a valuable analytical paper on certain iron ores occurring in France, and the products obtained therefrom in smelting. The presence of phosphorus was conclusively established in cast-iron.[1]

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[6] Schriften der Berlinischen Gesellschaft naturforschender Freunde. Berlin, 1781. 2, p. 334.
[7] Op. cit. 1782. 3, p. 380.
[8] Crell. Chem. Ann. 1784, 3d Part, p. 195.
[9] Ibid., 11th Part, 1785, p. 387.
[1] Jour. des Mines, 1806, 20, p. 381.

On the action of sulphur on iron containing phosphorus.—The following experiment has been made by Mr. Hochstätter in the same manner as the preceding, substituting sulphur for sulphide of iron :—

1. Phosphorized iron ($Fe^{12}P$ .... 200 grains.
Sulphur, not weighed, but in large excess.

A well-melted button with a bright surface was obtained, covered with a thin layer of sulphide of iron; it weighed, without the overlying layer, 193 grains: it was very hard, silver-white, and fine-grained in fracture; its powder was strongly attracted by the magnet. A portion of it was pulverized and digested hot with strong hydrochloric acid, when sulphuretted hydrogen was evolved, and a black insoluble residue remained, which dissolved easily after the addition of strong nitric acid. Its composition was as follows :—

Iron	89·54
Phosphorus	8·45
Sulphur	2·19
	100·18

On the fusion of iron containing sulphur with iron containing phosphorus.—The following experiments have been made by Mr. Hochstätter :—

	Grains.	Ratio of equivalents.
1. Phosphorized iron ($Fe^{12}P$)	184	1
Sulphide of iron (containing 39·4% of sulphur)...	277	12

These were finely powdered and intimately mixed together. The mixture was put into a covered and luted clay crucible contained within another also covered and luted, the space between the two being filled with the powder of burnt clay. The whole was exposed to a good red heat during about an hour. A well-melted button was found at the bottom of the crucible; it weighed 131 grains; it was hard, brittle, silver-white in fracture, and highly magnetic. This button was covered with a stratum in all respects resembling unchanged sulphide of iron; no trace of phosphorus was detected in it by the molybdate of ammonia test. A portion of the button was pulverized, and digested during several hours with strong hydrochloric acid, when sulphuretted hydrogen was dissolved, and a black residue remained similar to that produced by the action of the same acid on phosphide of iron of the formula $Fe^{12}P$. This residue completely dissolved in nitro-hydrochloric acid, with the exception of a minute quantity of siliceous matter. The composition of the button was as follows :—

Iron	87·83
Phosphorus	10·75
Sulphur	1·25
	99·83

	Grains.	Ratio of equivalents.
2. Phosphorized iron (Fe^4P)	286	1
Sulphide of iron (containing 39·4% of sulphur)...	352	4

The experiment was performed exactly like the preceding. A button was found at the bottom of the crucible, with a rounded, smooth upper

surface; it was very brittle; its fracture was dark-grey metallic, and coarse-grained; and its powder was scarcely attracted by the magnet. This button was covered with a stratum resembling unchanged sulphide, which weighed about 300 grains. A portion of the powder of the button was treated with hot dilute hydrochloric acid, when sulphuretted hydrogen was evolved, and a black residue remained. The fine powder dissolved slowly, yet completely, in nitro-hydrochloric acid, with the exception of a minute quantity of siliceous matter. The upper part of the overlying stratum contained no phosphorus, while a considerable amount was present in the lower part. The composition of the button was as follows:—

Iron	75·75
Phosphorus	19·19
Sulphur	4·92
	99·86

It may therefore be regarded as consisting of 83·39% of Fe^4P and 16·47% of Fe^4S^3, or $Fe^2S+2FeS$. By the action of dilute hydrochloric acid the whole of the sulphide of iron is extracted.

In the first of these experiments it appears that a portion of the iron was transferred from the phosphorized iron to the overlying sulphide, with a consequent relative increase in the proportion of phosphorus in the button.

A portion of each of the buttons obtained in the preceding experiments was melted with twice its weight of iron-filings, and in both cases homogeneous buttons were produced.

Phosphorized iron (Fe^4P)	300
Sulphur in large excess.	

A well-melted button was obtained, covered with a very thin layer of sulphide of iron; the two together weighed 309 grs. The button was very hard, brittle, silver-white and fine-grained in fracture, and its powder was slightly magnetic. It contained 4·52% of sulphur, which is nearly the same as that found in the button previously described.

On the action of fluoride of calcium on iron containing phosphorus.—The following experiments were made by Mr. Hochstätter:—An intimate mixture of phosphorized iron (Fe^4P) and fluoride of calcium was strongly heated in a clay crucible during an hour. A well-melted button was obtained, exactly similar in appearance to the original phosphorized iron. The crucible was much corroded, and in one place perforated. A similar experiment was made in a brasqued crucible, when a button was found under a well-melted layer of the fluoride. The button exactly resembled, and within ½ gr. had the same weight as the phosphorized iron employed.

On the action of carbon on iron containing phosphorus.—The following experiment was made by Mr. Hochstätter:—A brasqued crucible, containing 100 grs. of phosphorized iron (Fe^4P) in fine powder covered with charcoal, was exposed during about 1½ hour to a white heat. A well melted button was obtained, which weighed 89 grs.; its fracture was very finely-granular and nearly silver-white; its powder was

magnetic. By the action of hot dilute hydrochloric acid hydrogen was evolved, having the same odour as that produced by the action of the same acid on iron containing carbon. The resulting solution of iron was free from phosphorus. The button gave, on analysis, 18·1% of phosphorus, thus showing a loss of nearly 5% of that element, of which the original phosphorized iron contained 23·23%.

Phosphate of protoxide of iron. $2FeO, PO^5$.[2]—It is formed by the action of a slightly concentrated aqueous solution of phosphoric acid upon iron, hydrogen being evolved. The salt at first dissolves in the acid liquor, but as the latter becomes saturated with it, it is deposited as an amorphous, white, or whitish-grey mass. When, according to Debray, phosphoric acid is boiled with metallic iron, small colourless acicular crystals are deposited after a certain time, which become a little blue by exposure to the air. The same salt is obtained by boiling a solution of sulphate of protoxide of iron with phosphate of magnesia prepared in the cold. It has the formula $2FeO, PO^5, 3HO$, or $(2FeO, HO), PO^5+2HO$. When this salt is heated in water to 250° C., a salt of the formula $3FeO, PO^5+HO$ is produced; it has a deep green colour, and is in small crystalline grains.[3] By the addition of common phosphate of soda ($2NaO, HO+PO^5$) to a solution of sulphate of protoxide of iron, there is formed a white precipitate with a slight tinge of blue, which redissolves on agitation, and continues to do so until after the addition of a certain amount of the precipitant. If the liquor is filtered before the whole of the protoxide of iron is precipitated, the hydrated neutral salt is left on the filter as a white mass, which very quickly becomes bluish-grey on exposure to the air. The filtrate in contact with the air acquires a white cloudiness, which begins at the surface and extends downwards so long as any phosphate of protoxide remains in solution. In larger quantity it inclines to grey-blue, but becomes nearly white by washing and desiccation. According to Berzelius, it consists of the neutral phosphate of protoxide in combination with a subsalt; it is insoluble, and was supposed to have the formula $2FeO, PO^5+2(Fe^2O^3, 2PO^5)$. It is decomposed by caustic potash, which first separates brown sesquioxide of iron and afterwards black magnetic oxide. Phosphate of protoxide of iron dissolves slightly in water saturated with carbonic acid at the ordinary pressure of the atmosphere. The degree of solubility has been determined in my laboratory by Mr. T. Phillips: in one determination an imperial pint was found to dissolve 4·76 grains of the salt, and in another 4·72 grains. This corresponds to 0·54 part by weight in 1000 parts of solution. According to Pierre water saturated with carbonic acid dissolves nearly $\frac{1}{1000}$ of its weight of this phosphate.[4] Every precaution was taken to exclude air by a free current of carbonic acid during the experiments. On very gently heating the solution to expel the carbonic acid, the salt was precipitated in a granular state. A bottle containing a saturated solution of the salt in water impregnated with carbonic

[2] I have availed myself freely of Berzelius's description of this salt. Tr. 3, p. 574.

[3] Ann. de Chim. et de Phys. 3 ser. 61, p. 437. 1861.

[4] Ibid., 36, p. 70, 1852.

acid, together with a large quantity of undissolved salt, was set aside during two or three weeks. The deposit was then removed and carefully washed, when it was observed to consist of amorphous, in admixture with crystalline, phosphate. The crystals were bluish-white, small but sharply defined, and appeared very distinct under the microscope. They ultimately became dark greyish-blue. By heating 3 parts by weight of phosphate of protoxide of iron with 4 parts of iron filings, a button was procured which contained 2·35% of phosphorus. It much resembled the iron containing 1% of phosphorus previously described. This result was obtained by Mr. Hochstätter.

Tribasic phosphate of protoxide of iron. $3FeO, PO^5$.—According to Berzelius it is produced by pouring a solution of phosphate of soda of the formula $3NaO, PO^5$, drop by drop into a solution of a salt of protoxide of iron. At first it appears as a cheesy white precipitate, which on standing some time becomes semitransparent and gelatinous. When collected on a filter, it absorbs oxygen and begins instantly to turn blue or green. On pouring drop by drop a solution of sulphate of protoxide of iron into a solution of crystallized phosphate of soda, a precipitate is formed which Berzelius supposed to have the formula $2FeO, PO^5+2(3FeO, PO^5)$. Debray has prepared this salt by heating the preceding phosphate, of the formula $2FeO, PO^5+3HO$, to 250° C. He describes it as dark green, and as consisting of small crystalline grains.[5] Colourless crystallized tribasic phosphate of the formula $3FeO, PO^5+8HO$ has been found in Delaware, U.S. The blue mineral called Vivianite is a pseudomorph of this salt, and contains variable proportions of sesquioxide of iron resulting from atmospheric oxidation.[6] This mineral occurs beautifully crystallized as well as earthy. Many years ago I received from Dr. Johnstone, of Birmingham, a specimen of bone which had been dug up in making the railway in the meadows under Castle Bromwich. It was very friable, had a deep greyish-blue colour, and consisted chiefly of phosphoric acid in combination with protoxide and sesquioxide of iron. In an old mine in Upper Silesia was found a human skeleton, of which several of the bones presented in the interior crystals of Vivianite and blue-grey spots. The mine had been worked in the 13th century, and it is not known how long the skeleton may have been in it.[7] Sandberger found in horse's teeth taken out of a boggy meadow crystals of Vivianite from 1 to 1½ line in length; they were as clear as water, had a very bright lustre, and gradually acquired a smalts-blue colour by exposure to the air.[8] My friend Dr. Müller has in his possession a fragment of the bone of a sheep of which the internal cancellated part contains small acicular crystals of blue Vivianite having a remarkably bright lustre. This specimen was found near Schleitz, in Saxon Voigtland. According to Bischof when a solution of carbonate of protoxide of iron in water impregnated with carbonic acid is mixed

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[5] Ann. d. Chim. et de Phys. 3. s. 61, p. 437. 1861.

[6] Rammelsberg, Handb. d. Mineralchemie, 1860, p. 325.

[7] Bischof, Lehrb. d. Chem. u. Physik, Geologie, 1. p. 725.

[8] L. u. K. Jahresb. 1854, p. 858.

with a solution of phosphate of lime in the same menstruum and kept without access of air, turbidity occurs after some time, followed by the deposition of yellowish-white phosphate of protoxide of iron.[a] My friend Mr. Grill, of Sweden, informed me that he had seen Vivianite introduced into an iron-smelting furnace in Germany for the express purpose of producing cast-iron rich in phosphorus.

Phosphate of protoxide of iron and ammonia. $2FeO, PO^5+NH^3+12HO$.—It is prepared by adding ammonia to the solution of a salt of protoxide of iron mixed with a solution of phosphate of soda. Every precaution must be taken to exclude air, the ammonia and phosphate of soda should be in excess, and the whole should be well shaken in a stoppered bottle. The flocculent precipitate at first formed speedily becomes crystalline, like the corresponding magnesian salt. When pure the salt is white, but it acquires a green tint by exposure to the air.

Phosphate of sesquioxide of iron. $2Fe^2O^3, 3PO^5+8HO$.—Phosphate of sesquioxide, precipitated by the addition of phosphate of soda to a soluble sesquisalt of iron, was dissolved to saturation in an aqueous solution of phosphoric acid, and the whole was left in a stoppered bottle. After the lapse of a year, was deposited a mass of transparent, hard, cubical crystals, having a slight rosy tint, supposed to be due to manganese. On analysis they were found to have the formula stated above. When heated, the salt lost its water, and became opaque and dirty white in colour. It was insipid, insoluble in water, but soluble in hydrochloric acid as well as in caustic ammonia, with brown-yellow discolouration.[1]

Phosphate of sesquioxide of iron. Subphosphate of ferric oxide (Berzelius). Fe^2O^3, PO^5, or $2Fe^2O^3, 3PO^5+Fe^2O^3$.—Debray states that on exposing to the air the acid solution obtained by dissolving iron in phosphoric acid, and from which crystals of phosphate of protoxide have subsided on standing, a mammillated matter is deposited on the internal surface of the vessels, which is nearly white, and under the microscope presents evident traces of crystallization: it has the formula Fe^2O^3, PO^5+4HO.[2] It may be prepared by adding a solution of common phosphate of soda to a solution of sesquichloride of iron. It contains 4 equivalents of water. If the salt of iron be as neutral as possible, the liquor becomes acid. The phosphate is precipitated as white powder, which is insoluble in water, but dissolves in an excess of sesquichloride of iron, in mineral acids, and in carbonate of ammonia. Debray has obtained this salt as a mammillated deposit, showing a decided crystalline structure under the microscope, by leaving exposed to the air an acid aqueous solution of the phosphate of the formula $2FeO, PO^5+3HO$.[3] It undergoes no change by exposure to the air. At a red heat it becomes anhydrous and brown. It is completely decomposed when heated with soda or its carbonate, the whole of the phosphoric acid being separated as phosphate of soda. By the action of solution of potass it acquires the colour of sesquioxide

[a] Bischof, op. cit. 1, p. 725.

[1] Winckler, cited from Berzelius' Tr. 3, p. 593.

[2] Ann. de Chim. et de Phys. 3. s. 61, p. 437. 1861.

[3] Ibid.

of iron; and much of the acid, but not the whole, is removed. It is slowly turned red-brown by solution of carbonate of soda, and partially dissolves in a large excess of this solution.[4] It is rendered brown by ammonia, in which it gradually dissolves, provided excess of phosphate of soda or ammonia be present. The brown substance is a basic salt of the formula $3Fe^2O^3, 2PO^5+16HO$. Phosphate of sesquioxide of iron is a little soluble in a solution of a salt of the same oxide, but is insoluble in acetate of the protoxide of iron. Hence, on the addition of an alkaline acetate and sesquichloride of iron to a solution of phosphate of sesquioxide of iron in acids, some of the latter will be retained in solution; but this may be prevented by previously reducing it to phosphate of protoxide by sulphurous acid. The iron is thus completely, and by boiling, rapidly precipitated. Phosphate of sesquioxide of iron dissolves in 12,500 times its weight of water, charged with about its own volume of carbonic acid.[5] At a red heat, such as is obtained with an Argand spirit-lamp, this phosphate is reduced in a current of dry hydrogen to pyrophosphate of protoxide of iron, $2FeO, PO^5$; and when this salt is heated in a porcelain tube to whiteness in a current of hydrogen, water, phosphuretted hydrogen, phosphorous acid (PO^3), and phosphorus are evolved, and there remains an unfused mass, closely approximating to the formula Fe^8P^3.

The following phosphates of sesquioxide of iron have also been described:—

Sesquiferric phosphate, $3Fe^2O^3, 2PO^5$, or $2(2Fe^2O^3, 3PO^5) + 5Fe^2O^3$. (Berzelius).—It is precipitated by caustic ammonia from a solution of the salt of the formula Fe^2O^3, PO^5 in hydrochloric acid. It has the colour of rust.

Quadriferric phosphate, $2Fe^2O^3, PO^5$, or $2Fe^2O^3, 3PO^5 + 4Fe^2O^3$. (Berzelius).—It occurs naturally as an amorphous, brown, resin-like substance at Berneau in Belgium. It is stated to contain 24 equivalents of water.[6] It falls to pieces in water. Its mineralogical name is Delvauxite.

By the action of caustic potash upon any of the preceding phosphates, a substance is left which consists of 15 equivalents of sesquioxide of iron to 1 of phosphoric acid. Berzelius designates it *hyperferric phosphate*.

On the action of iron, at a high temperature, upon phosphate of lime in the presence of carbon.—This is a subject of much practical importance with reference to the smelting of iron-ores containing phosphate of lime. The following experiments have been made by Mr. Hochstätter:—Of thin iron, cut into small pieces, 700 grains were mixed with 870 grains of bone-ash and 600 of powdered anthracite. The mixture was exposed, under a layer of anthracite powder in a covered plumbago crucible, to a white heat during 1 hour. The product was a fritted mass containing the pieces of iron wire in their original form, except

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[4] H. Rose, Anal. Chem. 1851, 1, p. 123.

[5] Pierre, op. cit.

[6] Berzelius, Tr. 3, p. 594.

where they had been in contact, and there they had become welded together. The wire was brittle, and had a fine-grained and approximately silver-white fracture. On washing away with water the bone-ash and anthracite from the wire, phosphuretted hydrogen, not spontaneously inflammable, was evolved, thus proving that phosphide of calcium had been formed. The wire, after this treatment, was melted under plate-glass in a covered clay crucible, when a well-melted button, weighing 706 grains, and tinted blue on the surface, was obtained. It was very hard, brittle, and strongly magnetic. It was fine-grained, and approximately silver-white in fracture, except in spots here and there of a bluish tint. Its specific gravity was 7·08. By analysis it was found to be composed of 87·19% of iron, and 12·66% of phosphorus. This nearly corresponds to the formula Fe^8P.

Price and Nicholson, who were employed as chemists during 3 years at the Aberdare Iron-works, have published the results of some interesting and instructive experiments on this subject. They heated mixtures of pure hæmatite, phosphate of lime of known composition, flux, and coke in crucibles, and determined the proportion of phosphorus in the buttons obtained, and they have recorded their results in the table below:[7]—

No. of experiment.	Weight of hæmatite, in grammes.	Weight of phosphate of lime, in grammes.	Weight of flux, in grammes.	Weight of coke, in grammes.	Percentage of phosphorus in button.	
					Calculated.	Found.
I.	10·0	0·25	10·0	2·25	0·60	0·56
II.	10·0	0·75	10·0	2·25	1·83	1·60
III.	10·0	2·50	10·0	2·50	6·20	2·60
IV.	10·0	5·00	10·0	2·50	12·60	6·00

The same trustworthy chemists have also published the following table of the results of experiments on other matters containing phosphorus:—

		Lime.	Coke.	Flux.	Percentage of phosphorus in button.	
					Calculated.	Found.
	Grammes.	Grammes.	Grammes.	Grammes.		
V. Welsh black-band, ordinary quality,—calcined	10·0	3·5	1·75	..	0·82	0·81
VI. Argillaceous iron ore, very rich in phosphoric acid,—calcined	10·0	1·5	1·20	..	6·60	6·41
VII. Brown hæmatite, rich in phosphoric acid	10·0	..	..	10·0	6·90	6·70
VIII. Slag from puddling-furnace	10·0	..	2·0	10·0	13·60	12·50
IX. Slag from balling-furnace	10·0	..	2·0	10·0	2·27	2·25

[7] Phil. Mag. Dec. 1855. 10. p. 423.

The phosphoric acid in the ores was considered to be in combination with lime, and that in the slags to exist as phosphate of iron. The flux consisted of 2 parts of shale and 1 of lime. The time of exposure in the furnace was about the same in all these experiments. In Nos. I. and II. it is remarked that the quantity of phosphorus found agrees pretty well with that deduced by calculation, whilst in Nos. III. and IV. it falls considerably short. "That this," the authors state, "is owing to the length of time during which the reduction process is carried on, we have no doubt, as we have frequently repeated the assays with the same proportions, and have found the amount of phosphorus in the button to vary considerably, never having succeeded in obtaining more than $\frac{4}{5}$ths of the total quantity. If, however, the cementation were prolonged for a sufficient length of time, it is very probable that the whole of the phosphoric acid would be reduced."

On the action of iron, at a high temperature, upon phosphate of lime in the presence of carbon and free silica.—Wöhler had previously investigated this action. The following experiment by Mr. Hochstätter was conducted in the same manner as the last described. The proportions of the ingredients were 1000 grains of finely-cut iron-wire, 1250 grains of bone-ash, 625 grains of fine white sand, and 250 grains of anthracite powder. The product consisted of a button covered with imperfectly-melted slag containing shots of metal. The button and slag, freed from the excess of anthracite, were remelted in a covered clay crucible, when a well-melted button was procured, which weighed 984 grains. The slag was perfectly fused, and greyish white in colour. The button was crystalline on the surface, very hard, brittle, and strongly magnetic. Its fracture was fine-grained and greyish-white; it represented numerous small cavities lined with distinct crystals, having a blue iridescent tarnish. Its specific gravity was 7·25. By analysis it was found to consist of 85·78% of iron, and 14·10% of phosphorus. This approximates to the formula Fe^4P.

On the action of phosphorus on iron containing sulphur.—According to Janoyer, phosphorus does not expel sulphur from its combination with iron; and in proof of this he has recorded the following experiments which he made:[8]—

1. 10 grammes of very fine iron wire, cut into very small bits, were melted in an unbrasqued clay crucible with 0$^{grm.}$ 20 of iron-pyrites. The button was well melted, and contained 0·994% of sulphur.

2. 10 grammes of the same iron wire were melted in a similar manner with 0$^{grm.}$ 20 of iron-pyrites and 0$^{grm.}$ 20 of calcined bones. The button was well melted, and contained 1·005% of sulphur.

Manganese and Phosphorus.

As manganese frequently plays an important part in the metallurgy of iron, the following experiments made by Mr. Hochstätter may be appropriately introduced:—Of nearly pure Swedish pyrolusite (MnO^2)

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[8] Ann. des Mines, 5. s. 6. p. 165. 1854.

2000 grains were intimately mixed with 2000 grains of bone-ash, 1000 grains of fine white sand, and 600 grains of lamp black previously heated to redness in a covered crucible. The mixture was exposed in a covered clay crucible during 2 hours to a white heat. A well-melted button was obtained, covered with greenish-brown slag; it was hard, brittle, and feebly magnetic, from the presence doubtless of a little iron; its fracture was greyish-white with a reddish tinge, highly crystalline, and presented numerous well-defined crystals; its specific gravity was 5·53; it partly dissolved in hot hydrochloric acid, with evolution of hydrogen and phosphuretted hydrogen, and a black residue remained which was not examined; it was found to contain 21·97$^{\circ}/_{\circ}$ of phosphorus, which closely corresponds to the formula Mn^4P.

Iron and Arsenic.

Diarsenide of iron. Fe^2As.—The information published respecting this arsenide is not only unsatisfactory, but contradictory. Thus, according to Gehlen and Bergmann,[9] it does not fuse, whereas, according to Berthier, it is very fusible! Berthier has given the following description of it:—It is iron-grey, very fragile, presents on fracture large, very bright laminæ, is not magnetic, is very fusible, is not attacked by hydrochloric or sulphuric acid, is easily acted upon by nitric acid, and dissolves in nitro-hydrochloric acid, which converts it into arseniate of sesquioxide of iron. It is stable at 150° (W.P.) The same metallurgist states that this arsenide may be obtained by the following process:—A mixture of 100 parts by weight of iron-scale in powder, 50 of arsenious acid, 50 of carbonate of soda, and 20 of starch, is gradually heated to whiteness, when a button of arsenide, 100 parts by weight, is produced. This is fused with arsenious acid, carbonate of soda, and starch, when it absorbs 25 additional parts of arsenic. The second product is again fused with the same mixture, when it further takes up 15 parts of arsenic. The last product contains rather more arsenic than 1 equivalent to 2 of iron; it is somewhat bubbly, granular, and easily pulverizable.[1]

Arsenide of iron. FeAs.—This compound occurs in nature in several localities, viz. Reichenstein in Silesia, Fossum in Norway, Schladming in Styria, Breitenbrunn in Saxony, and Andreasberg in the Harz.[2] Another natural compound of the formula Fe^4As^3 is also admitted; it is met with at Reichenstein and at Geier in the Erzgebirge.[3] I shall consider only the first. The specific gravity of that from Reichenstein was found to range from 8·67 to 8·71. It crystallizes in the prismatic system (Miller), is metallic in lustre, white in colour, brittle, uneven in fracture, between apatite and felspar in hardness, and not attractable by the magnet. Heated in a close vessel it yields a sublimate of metallic arsenic, and a black, magnetic, metallic residue. Roasted with access of air, arsenious acid is copiously evolved from it, and

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[9] Gmelin, Handb. 5, p. 303.
[1] Berthier, T. 2, p. 203.
[2] G. Rose, Krystallo-chemische Mineralsystem, 1852, p. 53; Rammelsberg, Handb. d. Mineralchem. 1860, p. 19.
[3] Rammelsberg, op. cit. p. 18.

basic arseniate of sesquioxide of iron is left. It is attacked by nitric and nitro-hydrochloric acids, but not by hydrochloric or dilute sulphuric acid.

Biarsenide of iron. $FeAs^2$.—Iron reduced from sesquioxide of iron by hydrogen was heated to redness in the vapour of metallic arsenic. The experiment was made in a glass tube, through which a current of dry hydrogen was maintained. The tube was heated over a gas-combustion furnace, such as is now used in organic analysis. The iron having been first made red hot, the arsenic was volatilized, and its vapour carried over the iron by the current of hydrogen. Not the least incandescence occurred, though the iron rapidly and completely absorbed arsenic, of which none appeared to pass beyond the iron for a considerable time. The experiment was prolonged until the whole of the arsenic originally employed had been completely volatilized and carried beyond the iron, where it formed a copious deposit in the tube. When cold, the product was examined. It did not present any sign of fusion, but had become contracted in bulk; it continued quite as pulverulent as the reduced iron before it came in contact with arsenical vapour; it had a grey colour; not a trace was taken up by the magnet. Heated to redness in the air in one part, combustion is propagated through the mass, which burns like tinder, and evolves copious fumes of arsenic. When mixed with a little chlorate of potash, it ignites like gunpowder, evolving the odour of metallic arsenic. It is not sensibly acted upon either by hydrochloric or dilute sulphuric acid. It contained 14·06°/₀ of iron, which nearly corresponds to the formula $FeAs^2$ given above. Taking As = 75, the calculated per-centage from the formula is 15·70°/₀ of iron. This experiment was made in my laboratory by Mr. Richardson. In another similar experiment of the same kind the product was slightly sintered together, light steel-grey in colour, non-magnetic, and easily pulverizable. It was not acted upon by hydrochloric or dilute sulphuric acid. It was found to consist of 28·58°/₀ of iron, and 70·83°/₀ of arsenic. Both elements were quantitatively determined, the arsenic being weighed as arseniate of ammonia and magnesia. This product was again exposed for a long time to the action of the vapour of arsenic at a red heat. It had much the same appearance as before, and contained 26°/₀ of iron, which nearly corresponds to the formula FeAs.

Arsenide of iron of the formula Fe^4As.—Mixtures of iron wire, cut into small pieces, and excess of arsenic, were fused under plate-glass in covered clay crucibles. The products, which were well melted, closely resembled each other in appearance, were very brittle, light grey in colour, had a bright lustre, were close grained, and rather crystalline in fracture, yet differed much in composition.

Pieces of hoop iron were heated nearly to whiteness in a clay crucible, and then an excess of arsenic was dropped in. Immediately combination occurred with bright incandescence, and the iron melted completely. Two experiments were made, and the products were very similar to those previously obtained with iron wire, and yielded respectively 53·02°/₀ and 56·38°/₀ of iron. They were again heated under

plate-glass nearly to whiteness during about two hours, in clay crucibles with luted covers. The products remained apparently unchanged, and contained respectively 58·70% and 57·74% of iron; thus approximating to the formula Fe^4As, which yields 59·89% of arsenic.

Arsenide of iron of the formula Fe^6As.—In the *dry* assay of various ores containing arsenic, a *speise* is frequently formed, which consists essentially of iron and arsenic; and although it is produced under varying conditions, yet it is very similar in composition as well as appearance. The two following are selected by way of illustration, from numerous results obtained by Mr. Smith in the Metallurgical Laboratory :—

1. An auriferous ore, composed of iron-pyrites, arsenical pyrites, sesquioxide of iron, silica, etc., by fusion with borax, carbonate of soda, red lead, and charcoal, and stirring with an iron rod, gave a speise consisting per cent. of

Iron	70·93
Arsenic (by difference)	28·89
Sulphur (=FeS 0·49)	0·18

2. A sample of arsenical galena, by fusion with carbonate of soda, and the insertion of a piece of hoop-iron, gave a speise consisting per cent. of

Iron	72·17
Arsenic (by difference)	27·58
Sulphur (=FeS 0·69)	0·25

The composition of the speise in both cases may be nearly represented by the formula Fe^6As. Calculated from this formula, the percentage composition is

Iron	69·14
Arsenic	30·86

The speise is greyish white, hard, and very fragile. The fractured surface is bright, crystalline, and close in texture, resembling some varieties of white "refined iron." The temperature at which it is formed is much below the melting-point of wrought-iron, and the conditions of its formation are such that the arsenic can take up the maximum amount of iron. It is very liquid when melted, and takes sharply the impression of the mould in which it solidifies.

I am indebted to my friend Mr. Levick, of the Blaina Iron-works, for half of a cannon-ball, one of a great number from Sinope, which he had purchased as old iron. It is 5¾ in. in diameter; it is cleanly broken through the centre. The fractured surface presents a beautifully radiated crystalline structure, long, narrow, bright planes extending from the centre to the circumference. It is greyish white in colour, like white iron. There were several cavities due to bad casting. The borings from one of these balls were analysed by my friend Dr. Noad in 1859, and he has favoured me with the results of his analysis, which are as follow :—

Silicon	mere traces
Sulphur	0·57
Phosphorus	mere traces
Arsenic	16·20

A second analysis gave nearly the same results. Taking $As = 75$, the composition may be nearly represented by the formula $Fe^{14}As$. A piece of "puddled bar" made from these balls had "a glistening, highly crystalline fracture, and would not weld." It contained 0·87% of arsenic. The arsenic was weighed as ammonia-magnesian arseniate, after drying at 100° C.

The French found in the arsenal at Algiers, after their conquest, bombs and cannon-balls which were valueless as such, and were accordingly sent to France to be recast into projectiles, or converted into malleable iron; but it was soon ascertained that the metal of which they consisted was good for nothing. Berthier found in it a large quantity of arsenic; and his description of the appearance of the metal on fracture is nearly the same as that which I have employed in describing the ball from the Blaina Works. The balls were more fragile than the bombs. The results of Berthier's analyses are as follow:—

	Bombs.	Balls.
Arsenic	9·8	27·0
Carbon	1·5	1·0
Iron	88·7	72·0
	100·0	100·0
Specific gravity	7·585	7·65

They contained neither sulphur, manganese, copper, nor silicon. By boiling with hydrochloric acid the whole of the arsenic was left insoluble in the state of black, granular powder (believed to be FeAs), which only oxidized very slowly and very difficultly in the air, even when moistened with hydrochloric acid. But the metal, both of the bombs and shells, oxidized very rapidly on exposing it to the air, and wetting it frequently with water; on subsequently treating the oxidized matter by hydrochloric acid, the carbon remained mixed with a large quantity of arsenide of iron, and no arsenic was found in the solution, thus proving that no arseniate had been produced during oxidation. It was believed that these projectiles had been cast in Spain, but nothing was known respecting their date. Berthier was puzzled as to the ore from which the metal had been derived, and concluded that it could not have been *mispickel*, as he found no sulphur in his analyses. He therefore inferred that somewhere in Spain there must be abundant deposits of arsenide or arseniate of iron.[4] But with appropriate fluxes there would be no difficulty in obtaining from mispickel an alloy of iron and arsenic practically free from sulphur.

Arsenite of protoxide of iron. $2FeO, AsO^3$.—Berzelius describes it as a white precipitate which dissolves in caustic ammonia, oxidizes very rapidly during washing, and acquires the colour of yellow ochre. Heated in a close vessel in this state, it at first yields water and afterwards melts, when arsenious acid sublimes and there remains a rust-coloured fused mass.[5]

[4] Ann. d. Mines, 3. s. 11, p. 501, 1837. [5] Tr. 3, p. 581.

Arseniate of protoxide of iron. 2FeO, AsO^5.—According to Berzelius, it is thrown down as a white powder, which, in contact with air, becomes first brown and afterwards dirty green, the protoxide passing during this change into magnetic oxide of iron. Heated in a close vessel, the neutral salt acquires a dark grey colour, and yields a sublimate of arsenious acid; whilst the protoxide of iron passes to a higher degree of oxidation at the expense of the oxygen of the arsenic acid, which is thereby reduced to arsenious acid. Arseniate of protoxide of iron is slightly soluble in caustic ammonia, and the solution becomes green by exposure to the air; but it does not like the corresponding phosphate form an ammoniacal compound insoluble in water.[6]

Arseniate of sesquioxide of iron. $2Fe^2O^3$, $3AsO^5$.—Berzelius describes it as a white powder, insoluble in water, which becomes red when heated, and yields 17·68% of water or 12 equivalents. At an incipient red-heat, it evolves light feebly, and is afterwards paler and yellowish in colour. It dissolves in acids. While still in a moist state it also immediately dissolves when caustic ammonia is poured upon it, but after having been dried it is only soluble by digestion with that alkali; the solution is red and transparent, and when left in a warm place ammonia escapes from it without causing the precipitation of the arseniate; the liquor which has lost its odour remains limpid, and eventually dries into a fissured, transparent, ruby-coloured mass, which consists of a double sub-salt. This is partially decomposed by water, but dissolves in ammonia; and by dry distillation water, ammonia, and at length arsenious acid pass over, a green mass being left in the retort.[7] Berzelius does not state how he prepared this salt. By the addition of arseniate of potash to dilute sesquichloride of iron containing a little free acid, a copious precipitate of this salt occurs, which is not pure white, but has a pale buff tint. After gentle drying, it becomes somewhat deeper in colour. On heating it to redness in a closed tube, water is first given off, then a little crystalline sublimate of arsenious acid. It does not fuse, and retains very nearly the same colour as previously to calcination.

Arseniate of sesquioxide of iron. Sesquiferric arseniate (Berzelius).— Fe^2O^3, AsO^5.—The crystallized mineral "scorodite" has the formula Fe^2O^3, AsO^5+4HO. It is prepared by oxidizing the neutral arseniate of protoxide of iron by nitric acid, evaporating any nitric acid which may remain, or precipitating the salt by ammonia, by which it is neither dissolved nor decomposed. It is partially decomposed by potash, with the formation of a basic salt, similar in appearance to sesquioxide of iron precipitated by potash, but which is not decomposed by the further addition of potash. This salt contains 7·0% of arsenic acid, and 13·4% of water. Berzelius assigned to it the following very complicated formula:—

$$Fe^2O^3,\ 3AsO^5,\ 3HO + 25(2Fe^2O^3,\ 3HO).$$

Heated to incipient redness, it suddenly becomes incandescent.

[6] Berzelius, 3, p. 581. [7] Tr. 3, p. 602.

Arseniate of sesquioxide of iron. $2Fe^2O^3, AsO^5+12HO$.—It has been found near Freiberg, and is known to mineralogists under the name of "Eisensinter."[a]

The beautiful and well-known mineral, "cube-ore," according to Rammelsberg, has the following formula:—

$$4Fe^2O^3, 3AsO^5 + 15HO, \text{ or, as he writes it,}$$
$$3(Fe^2O^3, AsO^5 + 4aq) + Fe^2O^3, 3HO.$$

From the fine green colour which this mineral generally possesses it might reasonably have been expected to contain at least some protoxide of iron, as, indeed, was admitted by Berzelius. This instance of green coloration in a salt of sesquioxide of iron is so remarkably exceptional, that it requires to be established on evidence beyond the possibility of question.

Arsenic may be completely extracted from iron by deflagrating the finely powdered metal with nitre and carbonate of soda in a gold crucible. By washing the residue the arsenic is separated as soluble alkaline arseniate, while pure sesquioxide of iron is left. Similarly, arsenious or arsenic acid may be entirely removed from any salt of iron by fusion with fixed alkaline carbonate in a platinum crucible. Arsenic acid may also be perfectly precipitated in the state of ammonia-magnesian arseniate. The salt of iron must be dissolved in hydrochloric acid, peroxidized, treated with tartaric acid, then with excess of ammonia and a solution of a salt of magnesia previously mixed with sufficient ammoniacal salt to prevent the precipitation of magnesia by ammonia. After standing many hours the whole of the arsenic is deposited as the beautifully crystalline magnesian salt, which must be collected on a filter, washed with water strongly impregnated with ammonia, dried at 100°, and weighed. The salt thus dried has the formula $2MgO, NH^4O, AsO^5+HO$; it contains 60·53% of arsenic acid and 21·05% of magnesia. If the salt is heated *rapidly* to redness, it loses its water and ammonia; but the latter exerts a reducing action on the arsenic acid, and causes a loss of from 4% to 12% of arsenic.

Case-hardening iron or steel by arsenic.—I am indebted to Mr. C. Ekman, of Gothenburg, Sweden, for the following information on this subject. Rasped leather, horn, or other nitrogenous animal matter is mixed with a solution of arsenious acid dissolved in hydrochloric acid to the consistency of common porridge. The metal, as files, etc., is painted over with this composition about $\frac{1}{16}$ inch thick. It is then heated to bright redness in a muffle or iron cylinder, as is usual in hardening steel. A white surface of arsenide of iron is thus produced of great hardness. Ekman assured me that iron so treated is effectually preserved from rust; and, in proof, he mentioned the following fact. Fifteen years prior to 1847 two pieces of iron identical in all respects were selected, and one was case-hardened as above described. Both had been left during this long period exposed to precisely the same conditions; the

[a] Rammelsberg, Handb. 1860, p. 371.

piece not case-hardened was rusted throughout, while the other retained its original bright white surface. Should this statement be confirmed on further trial, this application of arsenic may be very valuable in a practical point of view. After receiving this information, many years ago I madė one or two experiments on the subject, but did not carry out the investigation as I proposed. I heated iron imbedded in a mixture of charcoal powder and an alkaline arsenite to redness during some time, and found that its surface was thereby rendered hard; but rusting was not prevented in consequence. I would not, however, pretend to set this result against the positive statement of so careful and trustworthy a man as Mr. Ekman.

Silicon.

There is no element of which it is more important to study the action in relation to the smelting and manufacture of iron than silicon; and yet our knowledge of this action is still very imperfect. Silicon has, however, of late begun to make itself felt as a power, not to be despised even by men who glory in styling themselves "practical," and affect contempt for everything "scientific." Silicon is not only a constant constituent of cast-iron, but, in the state of silica, plays a prominent part in the formation of slags, both in the reduction of the metal from the ore, and its subsequent conversion into wrought-iron. On this account, and because silicon has only been recently studied, I shall here present a concise description of its nature and properties. To Wöhler and Deville we are indebted almost exclusively for our knowledge of this element, which constitutes so large a proportion of the earth's crust.

Atomic weight. 22·2. According to Dumas 21·075.[*]

Silicon, according to Deville, exists in three allotropic states, the amorphous, graphitoidal, and diamond-like, so that in these respects it resembles carbon.[1]

Amorphous silicon.—Berzelius gave the following description of it:—It is a dark brown powder, does not conduct electricity, and in the dry state it strongly adheres to the fingers and all objects with which it comes in contact. It cannot be melted, but on exposure to a high temperature it undergoes considerable change, acquiring a higher specific gravity and darker colour. Berzelius regarded silicon, after having been strongly heated, as an allotropic variety, which he compared with that of carbon after similar treatment. Silicon before heating was represented by the symbol Siα, and after heating by the symbol Siβ.

Siα. It burns very vividly in the air, but only about a third of it is oxidized, the rest being protected by the coating of silica formed. It

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[*] L. u. K. Jahresb. 1859, p. 5.

[1] I subjoin references to the books which I have consulted on the subject of Silicon. I have not hesitated to translate literally whole passages, though seldom without some alteration; otherwise I should have introduced inverted commas. Berzelius, T. 1. p. 305 et seq.; Deville, Mémoire sur le Silicium, Ann. de Chim. et de Phys. 3. s. 49. pp. 62-78, 1857; Wöhler, Ann. de Chim. et de Phys. 3. s. 47, p. 116, 1856.

burns still more vividly in oxygen, with the formation of some water, and the production of a faint blue flame at its surface, thus showing the presence of hydrogen; and this occurs even after having taken the precaution previously to heat the silicon nearly to redness *in vacuo*. It is neither dissolved nor oxidized by sulphuric, nitric, hydrochloric, or nitrohydrochloric acids, not even at a boiling temperature; but it dissolves in hydrofluoric acid without the aid of heat, and in a hot concentrated solution of caustic potash with disengagement of hydrogen.

Siβ. On treating some Siα, after combustion, by hydrofluoric acid, the intermingled silica is dissolved, and there remains a dark chocolate-brown powder, which subsides in concentrated sulphuric acid, and is no longer in the least degree inflammable, either in atmospheric air or oxygen. It does not burn when in contact with chlorate of potash or nitre at a gentle red heat. Neither hydrofluoric acid nor solution of caustic potash acts upon it, even at the temperature of ebullition; but it dissolves very easily in a mixture of hydrofluoric and nitric acids, nitric oxide being evolved.

Berzelius describes several methods of preparing silicon,—heating potassium in fluoride of silicon,—heating fluoride of potassium and silicon with potassium,—heating potassium in the vapour of chloride of silicon and washing out the chloride of potassium in the product,—and by heating silica and potassium together. He speaks highly of the last process but one, and Deville recommends this as the best for obtaining pure amorphous silicon in large quantity. Deville's directions for conducting this process are as follow:—A wide tube of glass is completely lined internally with thin laminæ of mica, and then several small porcelain boats containing sodium are placed within it. The tube is connected with a tubulated retort by means of a cork. The neck of the retort is fitted with a cork through which pass a tube conveying dry hydrogen and a tube with a funnel mouth-piece: on introducing a little mercury into the retort the lower end of the latter tube becomes closed. A current of hydrogen is now sent through the apparatus, after which the tube is heated to redness; then the chloride of silicon which it is proposed to employ is poured into the retort through the funnel tube. Gentle heat is applied to the retort, so that the chloride of silicon may boil and its vapour pass over the sodium, by which it is absorbed with the emission of a considerable amount of light and heat. The operation is thus continued until the sodium appears to be exhausted, and until even the tube has become completely melted and distorted. Without this precaution, there would remain sodium unacted upon. The product, consisting of chloride of sodium and silicon, is washed during a long time with boiling water and then dried. Prepared in this way, according to Deville, the silicon perfectly resembles Siβ of Berzelius. When suspended in water and observed in sunlight, Deville states that it appears brilliant and micaceous. [Is it not, then, crystalline?] It fuses, contrary to the assertion of Berzelius as to its infusibility, at a temperature intermediate between the melting-points of cast-iron and steel; and in

fusing it small crucibles of carbon may be conveniently used. After fusion, it presents very remarkable indications of crystallization; the globules are striated parallel to large circles intersecting each other at angles which seem sensibly equal; they show no cleavage; their colour is a rather deep steel-grey, and their lustre is like that of specular iron ore; they not only scratch, but cut, glass with the greatest facility; and they are very brittle.

Deville also recommends the following process for the preparation of amorphous silicon. A glass, free from iron, is made by heating in a platinum crucible a mixture of 98 parts by weight of silica, 27 of Iceland spar, and 21 of pure fused carbonate of potash. This glass coarsely pounded is introduced, along with a quantity of sodium insufficient to decompose even half of it, into a tube of common glass which is heated just to redness. There is no evolution of heat during the reduction of the silica, and the operation is completed when the sodium interposed between the particles of glass has disappeared. The black mass thus produced is put into a carbon crucible, enclosed within a covered ordinary crucible, and subjected to an intense heat in a blast-furnace. The silicon will be found diffused through the melted obsidian-like glass, in the form of small, very brittle, steel-grey coloured globules, which are readily extracted by breaking up the vitreous mass into small fragments.

Buff and Wöhler give the following process for making amorphous silicon from the fluoride of sodium and silicon (fluosilicate of soda). The salt is mixed with about its own weight of common salt which has been fused. To the mixture sodium in small fragments is added, and the whole is thrown into a red-hot clay crucible, which is covered and heated to low redness. After cooling, the mass is boiled with water acidulated with hydrochloric acid, and the silicon left is afterwards purified from silica with hydrofluoric acid.[3]

Silicon may be prepared by passing the current from a battery of four of Bunsen's cells through a melted mixture of equal parts by weight of fluoride of potassium and fluoride of sodium, in which calcined silica has been previously dissolved. The silicon appears at the negative pole, and oxygen escapes at the positive pole. Carbon electrodes may be used in this experiment. Silica dissolves readily when added to the mixed fluorides in fusion.

There seems to me to be a little discrepancy in Deville's description of amorphous silicon. Thus, in reference to the silicon formed by the action of sodium at a red-heat on chloride of silicon, he writes, "The matter which one collects perfectly resembles silicon, which Berzelius compares with carbon strongly heated." Now, Deville designates this *amorphous* silicon; yet under the head of graphitoidal silicon he states that this variety "participates in all the properties which Berzelius assigns to silicon strongly heated, except perhaps that it offers still greater resistance to the burning action of oxygen." If I am correct, the methods described by Deville for the preparation of

[3] Ann. de Chim. et de Phys. 3. s. 52, p. 283, 1858.

amorphous silicon, really yield a crystalline silicon, and not the true Si*a* of Berzelius. But it may be doubted whether this variety has ever been procured absolutely pure, and at the same time absolutely amorphous.

Graphitoidal silicon.—This beautiful substance was first obtained by Deville in admixture with aluminium. Wöhler was the first to describe a satisfactory method for preparing it. This consists in fusing in a Hessian crucible, at the melting-point of silver, aluminium with from 20 to 40 times its weight of thoroughly dry double fluoride of potassium and silicon. The mass is kept melted during a quarter of an hour, and left at rest to cool. On breaking the crucible will be found in a white or greyish matrix a metallic button, having a dark iron-grey colour; it consists of aluminium, in which is imbedded a large quantity of crystalline silicon. The button is broken up, but not pulverized, and then treated with hot concentrated hydrochloric acid until hydrogen ceases to be disengaged; or it may be remelted, and the aluminium cautiously poured off from the silicon, which will be found to have subsided and accumulated at the bottom. The molten aluminium acts simply the part of a solvent, but the whole of the silicon separates in a crystalline form on solidification. The insoluble residue is heated in a platinum capsule with tolerably strong hydrofluoric acid, which extracts the silicic acid contained in the former. A crystalline substance is thus procured, which requires only to be washed and dried. This is graphitoidal silicon, which separates from aluminium on solidification, just as graphite separates from cast-iron under similar conditions. In several experiments, 100 parts by weight of aluminium have yielded from 70 to 80 of the siliciferous alloy, containing from 65% to 75% of crystalline silicon.

Thus prepared, it is in the form of brilliant opaque laminæ, exactly resembling the graphite from iron-smelting furnaces, except that its lustre is more highly metallic and its colour inclines to lead grey. It is sometimes procured in distinct hexagonal plates. It is very hard, scratching glass, but not topaz. At 100° C. its specific gravity is 2·490. It conducts electricity well. It may be subjected to a red-white heat in oxygen, without burning or changing in weight. Heated to redness with carbonate of potash, it decomposes the carbonic acid with the emission of vivid light, and is converted into silicic acid. Heated to incipient redness in a current of dry chlorine, it burns completely, and is converted into chloride of silicon; and when similarly treated in a current of moist chlorine, crystals of silicon are changed into pseudomorphs of transparent but easily friable silica.[4]

Diamond-like, or octahedral silicon.—Silicon dissolves in molten zinc, and separates during solidification in beautifully-formed octahedral crystals, belonging to the cubical system, and not in hexagonal plates, as from aluminium. The following directions are given by Wöhler and Deville for the preparation of these crystals:—A carefully-made mixture of 300 parts by weight of fluoride of potassium and silicon, 80

[4] L. u. K. Jahresb. 1859, p. 155.

of sodium cut into small bits, and 400 of granulated zinc, is heated to strong redness in a covered clay crucible until the contents appear well melted, after which it is left slowly to cool. In order to prevent perforation of the crucible, the operation must be conducted as quickly as possible. Almost the whole of the crystallized silicon will be found collected in the upper part of the button of zinc. The button is heated so as merely to fuse the zinc, which is then poured off, leaving the silicon with some adherent zinc in the crucible: the zinc thus separated may be applied again for a similar purpose. The silicon is treated with concentrated hydrochloric acid, which dissolves the zinc and any iron which may be present; but any lead which may have existed in the zinc will remain, and must be removed by strong nitric acid, after which the silicon must be thoroughly washed with water. It must then be treated with hydrofluoric acid to free it from oxide of silicon and any adherent bits of the crucible, washed, and dried, when it may be regarded as pure. Should it be desired to melt it, it is mixed with some fluoride of potassium and silicon, put into one crucible contained within another, covered with coarsely-pounded glass free from lead, and heated for some time at the melting-point of cast-iron. It is then taken out of the furnace, and, when it has ceased to be red-hot, it is plunged into cold water in order to render the glass more friable. The crucible is carefully broken, and any portions of it adherent to the lump of silicon are detached, after which the latter must be digested for a long time in concentrated hydrofluoric acid. Melted as well as crystallized silicon is attacked and dissolved by a mixture of nitric and hydrofluoric acids.[5] A contributor to a chemical journal announces that he could not succeed in obtaining crystallized silicon by this process! I have tried it repeatedly, and never failed to procure beautiful crystals. No acid acts upon it. I have kept it in sulphuric acid at or near the boiling-point during about 20 hours without perceiving the slightest action. A strong solution of potash or soda slowly dissolves it with evolution of hydrogen. When thrown into molten hydrate of potash in a gold crucible, vigorous action, attended with much effervescence, occurs. It is a beautiful experiment to drop these crystals into a molten mixture of potash and nitre in a gold crucible; there is incandescence with purplish light, as each crystal falls in and suddenly disappears: where much is added at a time the whole surface of the melted mass becomes covered with purplish flame. The product is limpid and colourless. I found no action produced by heating it to redness in the vapour of sulphur.

The vapour of chloride of silicon is passed over aluminium heated to bright redness in a porcelain tube. Precisely the same kind of apparatus is used as that previously described for the preparation of amorphous silicon, the only differences being that a porcelain, instead of a glass, tube is employed, and aluminium instead of sodium. The vapour of the chloride of silicon is decomposed by contact with the aluminium, heat is evolved, and small bright sparks appear here

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[5] L. u. K. Jahresb., 1861, p. 202.

and there (s'agitent) in the tube. "There is evidently," says Deville, "projection of metallic matter, which without doubt is difficult of explanation, but which explains the following equally strange phenomenon. On withdrawing the little boats, they are found to be exactly filled with large and beautiful needles of silicon, which are disposed in the tube in such a manner as might lead to the belief that silicon or aluminium is volatile. This appearance is only explicable by the projections of matter which take place at the moment of the reaction. These needles are often as vividly iridescent as specular iron ore, which, moreover, silicon much resembles in colour and hardness. The silicon has a dark iron-grey colour with a reddish reflection; it scratches glass very deeply, and may even cut glass like the diamond."

The form of these crystals was at first supposed to be rhombohedral; but Senarmont and Descloizeaux examined them, and ascertained that they belonged to the cubical system. Descloizeaux, in some of Deville's specimens, met with regular nearly isolated octahedrons, which were measurable. The crystals are superimposed upon each other in such a manner as to form singular elongated groups.[6] Their termination consists of three faces, simulating one of the commonest forms of the rhombohedral system, in which carbonate of lime and even quartz often occur. The regular hexagonal prisms of this crystallized silicon are only the faces of the rhombic dodecahedron developed according to a very simple law; and, perhaps, the beautiful crystals of Wöhler with a hexagonal base belong to the regular or cubical system.[7] Deville further expresses an opinion that silicon crystallized by fusion, and which often occurs in the form of a six-sided pyramid, exactly resembles the diamond with curved faces, and may, like it, be referred to a solid with 48 faces, derived from the regular octahedron.

By the action of aluminium on chloride of silicon at a high temperature, chloride of aluminium is produced, and, being volatile, is evolved. Similarly, when chloride of carbon is passed over melted cast-iron, brilliant, iridescent, hexagonal plates of graphite are copiously formed, of which the lustre much exceeds that of ordinary artificial graphite. When the vapour of chloride of silicon is passed through a porcelain tube heated to redness, and containing metallic zinc, it is decomposed with the separation of shining crystals of silicon; and through the mass of zinc which condenses in the cooler part of the tube crystals of graphitoidal silicon are diffused.[8] The existence of true graphitoidal silicon appears doubtful after the foregoing remark.

We are indebted to Buff and Wöhler for the discovery of several compounds of silicon of great scientific interest, of which I subjoin a description.[9]

Siliciuretted hydrogen. SiH'?—It was evolved in admixture with a large quantity of free hydrogen from the surface of aluminium con-

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[6] Ann. de Chim. et de Phys. 3. s. 47, p. 169, 1853.
[7] Deville, op. cit. p. 75.
[8] Becketoff, L. u. K. Jahresb. 1859, p. 196.
[9] Ann. de Chim. et de Phys 3. s. 52, pp. 257-285. 1858.

taining silicon, employed as the positive electrode in an aqueous solution of chloride of sodium, through which a current of electricity was passed from 8 or 12 Bunsen cells. It is also formed by dissolving siliciuretted aluminium in dilute hydrochloric acid; but the gas thus disengaged does not contain sufficient siliciuretted hydrogen to inflame spontaneously, not even when aluminium saturated with silicon is employed, the greater part of the silicon separating partly in lamellar crystals, and partly in the state of very fine black powder. Siliciuretted hydrogen is likewise generated in small quantity by the action of hydrochloric acid on siliciuretted manganese.[1] It spontaneously inflames in contact with air, producing copious white vapour due to the formation of silicic acid. It was clearly proved that hydrogen in combining with silicon decreases in volume. Siliciuretted hydrogen is insoluble in pure water deprived of air, as well as in salt water. It is not acted upon by hydrochloric or dilute sulphuric acid. It is decomposed at the ordinary temperature when agitated with solution of caustic potash. It detonates violently with gaseous chlorine. It suffers no change by admixture with protoxide or deutoxide of nitrogen. It is decomposed at a red-heat with deposition of amorphous silicon. It causes precipitates in several metallic solutions, such as those of sulphate of copper, nitrate of silver, and chloride of palladium; but it has no action on solution of acetate of lead or chloride of platinum. On the surface of a solution of the salt of copper, and on surfaces moistened by it, it immediately causes a dark red pellicle of copper, which, in thin laminæ, appears brown-yellow by transmitted light. The silicide of copper thus formed speedily changes in the air into lemon-coloured silicate of copper. Moistened with dilute nitric acid, it is immediately decomposed, and metallic copper is deposited. Hydrochloric acid dissolves it with evolution of hydrogen, and the deposition of oxide of silicon. In solution of caustic potash, it produces a lively effervescence of hydrogen, and copper free from silicon subsides. But as it disengages hydrogen even with ammonia, it appears to contain in admixture some oxide of silicon. Siliciuretted hydrogen precipitates from solution of nitrate of silver a black substance, which is doubtless silicide of silver, but some silver is also reduced to the metallic state. With solution of palladium blackish-grey palladium free from silicon is separated.

The best process at present known for preparing siliciuretted hydrogen is that found in Wöhler's laboratory by Dr. C. Martius, who observed that on treating with hydrochloric acid a slag produced in making magnesium by Deville's method, spontaneously inflammable gas was disengaged.[2] It may be obtained by the following process as easily as phosphuretted hydrogen: 30 grammes of fused chloride of magnesium, 40 grms. of fluoride of sodium and silicon (fluosilicate of soda) strongly dried, and 10 grms. of fused chloride of sodium, are reduced to fine powder in a hot mortar and intimately mixed. The

[1] Ann. de Chim. et de Phys. 3. s. 44, p. 90. 1858.

[2] Ibid. s. 54, p. 218. 1858.

mixture is put into a heated glass vessel, which may be closed, and 20 grms. of sodium cut up into fragments as small as possible are added, and shaken with the powder, after which the contents of the vessel are instantly dropped into a Hessian crucible previously made red-hot. The crucible is covered and further somewhat heated, when the reaction immediately manifests itself by repeated cracklings. As soon as this noise has ceased, and flames of sodium no longer appear above the cover, the crucible is taken out of the fire, left to cool, and then broken. The product is a blackish grey melted mass, filled with globules and plates (lamelles), having a metallic lustre and deep iron-grey colour; it contains, in addition to silicon, a silicide of magnesium of the formula Mg^2Si, and composed of 47·1 % of silicon and 52·9 % of magnesium. This product is coarsely pulverized and put into a two-necked bottle, of which one neck is provided with a funnel-mouthed tube passing to the bottom of the bottle, and the other with a short and wide delivery tube. The apparatus is filled up with water, and then placed in the pneumatic trough, above the level of the water, so that the delivery tube may be quite full of water, and not a single bubble of air may remain in the apparatus. A receiver filled with water having been placed over the mouth of the delivery tube, strong hydrochloric acid is poured into the funnel-mouthed tube, taking care that not a bubble of air enters the bottle. Gas is copiously evolved with great violence, producing a strong froth, which passes into the receiver, but subsides in a short time, when the gas may be transferred into another receiver, and so obtained free from froth. Only water which has been deprived of air by boiling should be used in this process; for if aërated water is used, the gas produced becomes nebulous, and soon loses its property of igniting spontaneously. The gas may be procured dry by passing it through a chloride of calcium tube into a receiver over the mercurial trough.

Thus prepared, every bubble of gas, as it escapes into the air, inflames with a loud explosion, followed by white smoke. The silicic acid resulting from this combustion produces, exactly as in the combustion of phosphuretted hydrogen, beautiful rings, which diffuse themselves in the air in the form of threads and flocks, often coloured brown by unburnt silicon. If the gas escapes into the air as it leaves the end of the delivery tube, it produces copious very brilliant white flame.

Hydrochlorate of chloride of silicon. Si^2Cl^3+2HCl.—It is a volatile, colourless, very mobile liquid, which is produced by heating crystalline silicon to incipient redness in hydrochloric acid gas. It is decomposed by water with the formation of a white oxide of silicon. Hence, it fumes much on exposure to the air, covering surrounding objects with a white deposit. It evolves a suffocating odour. It boils at 42° C., and its specific gravity is 1·65. It is a non-conductor of electricity. Its vapour is as inflammable as that of ether, and burns with a greenish feebly luminous flame, diffusing fumes of silica and hydrochloric acid. Its vapour is very easily decomposed at a red heat with separation of amorphous silicon, which is deposited on the in-

ternal surface of the tube in which the experiment may be made as a brown mirror-like lining; chloride of silicon ($SiCl^2$) and hydrochloric acid are also evolved. Alcohol and ether absorb this compound in large quantity without any separation of oxide of silicon.

Analogous compounds with bromine and iodine have been made (Si^2Br^3+2HBr and Si^2I^3+2HI). The bromine compound is a fuming colourless liquid. The iodine compound is solid, brittle, deep red in colour, and fumes strongly in contact with the air; it is very fusible, and crystallizes on cooling; at a higher temperature it boils, and may be distilled. Water, which instantly colours it vermilion, only decomposes it slowly. It is very soluble in bisulphide of carbon.

Hydrated oxide of silicon. Si^2O^3+2HO.—It is this compound which is produced under the conditions previously described. It may be easily obtained by passing simultaneously into water an excess of gaseous hydrochloric acid and hydrogen saturated with the compound Si^2Cl^3+2HCl. The water should be kept at 0° C., because at ordinary temperatures it begins to decompose in contact with water. The oxide is washed on a filter with water at 0° C., pressed at first gradually and afterwards strongly between bibulous paper, and then dried at the ordinary temperature, or by preference over sulphuric acid. Thus prepared it is amorphous and snow-white, very light, bulky, and floats on water. It subsides in ether. Caustic alkalies, alkaline carbonates, and even ammonia, convert it into alkaline silicate, with lively effervescence, due to the liberation of hydrogen. Acids, even strong nitric acid, exert no action upon it, with the exception of hydrofluoric acid, which alone dissolves it with copious disengagement of hydrogen. It may be heated to 300° C. without losing its water or undergoing any change. Heated more strongly it takes fire, emitting sparks and diffusing a phosphorescent light; while at the same time hydrogen is evolved which burns with explosion. In oxygen it burns with the production of heat and brilliant light. Heated in an open crucible it burns equally; but the silica resulting from the combustion is coloured more or less brown by amorphous silicon, and the sides of the vessel are coated with silica. On heating this hydrated oxide of silicon, siliciuretted hydrogen is readily disengaged, but only at the temperature at which that gas itself decomposes. When heated in an open tube, there escapes into the air a fuming gas, which does not spontaneously ignite on account of the hydrogen mixed with it; but on lighting this gas, it burns, yielding a residue of silica. The silica remaining in the tube is coloured brown by silicon. When hydrated oxide of silicon is heated to redness in a current of hydrogen, silicon is separated as a brown mirror-like coating; and the gas when lighted burns, depositing a mass of silica on a plate of glass held in the flame. The following equation explains the reaction:—

$$3(Si^2O^3 + 2HO) = 5SiO^2 + 5H + SiH.$$

Hydrated oxide of silicon is slightly soluble in water. The acid filtrate separated in preparing the oxide afterwards undergoes a sort of fermentation; it becomes filled with bubbles of hydrogen, which rise to

the surface and escape gradually in such quantity, that, when the liquid is placed in a covered vessel, the cover is raised. This decomposition is promoted by heat. Ammonia added to this solution immediately causes a copious evolution of hydrogen. This solution of oxide of silicon reduces chloride of gold; it precipitates from solution of chloride of palladium a black powder, which is probably a mixture of the metal and protosilicate of palladium. With nitrate of silver, it at first occasions a precipitate of chloride of silver, then a dark brown precipitate, probably identical, though less deep in colour, with the matter obtained in treating washed oxide of silver with solution of nitrate of silver; ammonia immediately turns this matter black. The black matter is regarded as silicate of protoxide of silver; it is insoluble in ammonia, and only difficultly decomposed by nitric acid with the separation of silica; it becomes grey by calcination, and, if heated after calcination with nitric acid, it is changed into brownish-yellow silicate of oxide of silver, which is not attacked by the same acid even when boiling; with borax before the blow-pipe it gives a yellow bead with bluish reflections. When the acid filtrate containing oxide of silicon is mixed with a salt of protoxide of copper and a little alkali is afterwards added, hydrated yellow dioxide of copper is precipitated. From solutions of selenious and tellurous acids in hydrochloric acid, it separates red selenium and grey tellurium. In a solution of chloride of mercury it throws down dichloride, which is crystalline and chatoyant, and which left in contact with an excess of the solution passes gradually to the state of grey pulverulent metal. Mixed with sulphurous acid, it causes turbidity, with the gradual deposition of white sulphur. It instantly decolourizes a solution of permanganate of potash; but it has no action on solutions of chromic acid, platinum, iridium, and indigo.

Buff and Wöhler obtained positive evidence in favour of the existence of a lower oxide of silicon, probably having the formula Si^2O^4+3HO, or $SiO+Si^2O^3+3HO$. In some specimens of the hydrated oxide they found more silicon than is indicated by the formula Si^2O^3+3HO. They considered that the reducing actions above described were due to a solution of the lower oxide.

Silicon and nitrogen.—According to Wöhler and Deville, silicon, like boron and titanium, combines at a very high temperature with nitrogen. A small Hessian crucible containing crystallized silicon was put into a larger and well covered crucible of the same kind, and the space between the two was filled with freshly ignited charcoal powder. The whole was exposed during an hour to the highest temperature of a coke fire. Most of the silicon was thereby changed into a loose bluish mass, which was covered with a fibrous easily separable substance, resembling the mineral termed *mountain cork;* and was white, except on the surface, where it was coated with microscopic dark tombac-coloured crystals, of which the nature was not ascertained. Both this white substance and the bluish mass evolved much ammonia when acted upon by molten potash. The bluish mass contained nitride of silicon mixed with free silicon; the latter may be separated from the

former by heating to redness in a current of chlorine, which has no action at this temperature either upon the nitride of silicon or boron. When the nitride of silicon was heated to strong redness in a stream of moist carbonic acid gas, carbonate of ammonia escaped and amorphous silica remained: this decomposition was complete, though it only took place slowly. Nitride of silicon prepared from chloride of silicon gradually decomposes water at the ordinary temperature. Wöhler and Deville suggest that nitride of silicon may possibly have played an important part in the formation of the earth's crust, and have been converted by the action of water into silica and ammonia.[3]

Manganese and Silicon.

Brunner was the first to describe the properties of manganese reduced from its fluoride or chloride by sodium. He found the metal to differ much from that reduced from oxide of manganese by carbon, which falls to powder when exposed to the air, and decomposes water at ordinary temperatures. It fuses at the melting point of cast-iron. It is very hard, susceptible of taking as fine a polish as steel, and does not tarnish in the air. The metal contained silicon, which in twelve different trials ranged from 0·6 % to 6·4 %. By the addition of fluoride of potassium and silicon, and silica, he procured metal containing 10 % of silicon. Wöhler examined specimens prepared by Brunner, and confirmed the accuracy of his observations. He has published the following results of his experiments. A mixture of about equal weights of fluoride of manganese, silicate of potash, cryolite ($3Na, Fl + Al^2Fl^3$), and sodium, is strongly pressed into a thoroughly dry earthen crucible, and then covered with a layer of the chloride of potassium or sodium. The crucible is put into a good air furnace, and after reduction has taken place the temperature is raised. A button of metal is thus formed, which is very hard, brittle, and somewhat foliated in structure. No free silicon was observed in it. The metal contained 11·7 % of silicon. It dissolves with difficulty in hydrochloric acid, because each fragment becomes coated with a greyish layer of oxide of silicon, which prevents the further action of the acid, and must be removed by solution of caustic potash. This oxide is perfectly amorphous, and much denser than that obtained with manganese, poorer in silicon, or from chloride of silicon; and under the microscope it does not appear in the least crystalline. The hydrogen evolved from it by the action of hydrochloric acid contains siliciuretted hydrogen, but not in sufficient quantity to render it spontaneously inflammable. Hydrofluoric acid dissolves the silicide of manganese, with the disengagement of very fetid hydrogen.

Another specimen prepared by calcining a mixture of a double chloride of sodium and manganese with fluor-spar, silicate of potash, and with sodium, contained 13 % of silicon. The metal was well melted, very brittle, and presented a few small blisters lined with steel-coloured prismatic crystals. Another experiment was made with a mixture of fused chloride of manganese, fluor-spar, fluoride of potas-

[3] L. u. K. Jahresb. 1859, p. 154.

sium and silicon (fluosilicate of potash), and sodium. The button, which had been rapidly cooled, was nearly as white as silver, and very brittle; its fracture was conchoidal and very bright. Wöhler supposed that these last two properties may have possibly depended on the fact that the metal had not been left to cool slowly. It contained only 6·48 % of silicon. A last experiment was made by melting a mixture of chloride of manganese, sodium, fine sand, and cryolite; the last two substances in the ratio of 22 : 26. The button obtained was slightly yellowish, showed signs of crystalline structure, and contained 11·37 % of silicon.[4] Two experiments on a larger scale were made with double chloride of sodium and manganese, fluoride of potassium and silicon, and sodium, *without* fluor-spar, at a temperature longer sustained and higher than previously; but no traces of metal were found, although, from the violent noise at the beginning of the operation, reduction might have been expected. Hence, according to Wöhler, it would seem that the manganese at first reduced, acted in its turn at this higher temperature upon the chloride of sodium, forming chloride of manganese and setting free sodium; while it could not decompose the fluoride of sodium formed when fluoride of manganese was employed. Brunner endeavoured to determine whether the peculiar properties of the manganese which he obtained were due to the presence of silicon. Error might be anticipated from the use of earthen crucibles. On melting the manganese in coarse powder with chloride of sodium, with 1 % of chlorate of potash, and keeping the whole in fusion at a red-white heat during only 10 minutes, he succeeded in diminishing the silicon to about 0·1 %. If silicon be the cause of the peculiarity of the manganese formed by this method of reduction, it is a very remarkable fact, which may become of great practical value, especially in relation to the metallurgy of iron. Sefström procured manganese containing from 8 % to 10 % of silicon, by reducing oxide of manganese in admixture with silica and carbon. He describes the metal as steel-grey in colour, and as insoluble even in nitro-hydrochloric acid.[5]

Iron and Silicon.

At present, so far as I am aware, nothing is known concerning pure silicide of iron. All the compounds of silicon and iron, which, as yet, I have had the opportunity of examining, have been prepared by the reducing action of carbon, and have not been free from this element. When silica in admixture with iron and carbon is exposed to a high temperature, it is reduced in a greater or less degree, the silicon combining with the iron; but, according to my experience, no reduction takes place when silica and iron without carbon are heated together, even at the highest temperatures of furnaces. I am not aware whether this silicide has been made by directly heating together silicon and metallic iron. I have tried to obtain it by strongly heating fluoride of potassium and silicon with sodium, and finely divided

[4] Ann. de Chim. et de Phys. 3. s. 51, p. 90. 1858. Also op. cit. 53, p. 359.

[5] Berzelius, Tr. 2, p. 730.

iron prepared by reducing sesquioxide of iron in hydrogen; but I did not succeed, though silicide of copper may, as has been previously stated, be readily produced by this process with the substitution of copper for iron. Nor have I succeeded any better by passing dry hydrofluosilicic acid gas over iron wire in a porcelain tube heated much beyond redness; nor again in attempting to reduce tribasic silicate of protoxide of iron by sodium at a high temperature. When silicate of protoxide of iron is reduced on the large scale in blast furnaces, it does not appear to produce what may properly be called silicious iron. Thus Mr. Riley, formerly chemist at the Dowlais Iron-works, informs me that he found only 1·07 % of silicon in white pig-iron derived wholly from "refinery cinder" (which is a silicate of protoxide of iron), in admixture with a little mine shale. I find no difficulty in producing highly siliciferous iron by heating to whiteness silica in contact with metallic iron, or sesquioxide of iron and charcoal in excess.

Reduction of silica by carbon in the presence of oxide of iron and other bases.—This subject, which is one of great practical importance, has of late been elucidated by experiments on the large as well as the small scale. It appears to be established that free silica, unaccompanied with earthy matters with which it might combine to form slags, such as carbonate of lime and clay, tends to produce iron rich in silicon, especially if the temperature be very high and much carbon be present.

The two following experiments on this point have been made by Mr. Hochstätter in my laboratory:—A pure variety of red hæmatite (kidney-ore), containing on the average about 69 % of iron, was exposed, in intimate admixture with fine sand and charcoal in a covered clay crucible, to a high temperature during 1½ hour. The product was a fritted mass, in which small brilliant metallic globules were diffused throughout; and, as these were magnetic, they were separated by means of the magnet, as far as practicable, from adherent sand and charcoal, and then fused with the addition of a little alumina and magnesia. Well-melted buttons were thus obtained, covered with well-melted, easily detachable slag. The metal was hard and brittle; its fracture was light-grey, highly crystalline, and presented aggregations of minute bright faces set at various angles, so that on varying the direction of the incident light every part appeared bright in succession, although in any one position the fracture seemed to consist of about an equal proportion of dull and grey particles. By the action of boiling hydrochloric acid upon the powder of the buttons, hydrogen was evolved, which produced no deposit in a red-hot, hard glass tube, through which it was passed during half an hour. Perfect decomposition of the powder could not be effected by this acid.

No. of experiment.	Weight of materials taken in grains.			Weight of metallic button in grains.	Specific gravity of button.	Silicon per cent.
	Hæmatite.	Sand.	Charcoal.			
I.	2000	2310	900	961	6·94	12·26[a]
II.	6000	4000	2700	1945	7·23	8·96

[a] The silica was not perfectly pure, but contained a minute quantity of oxide of iron.

The button in No. II. was lighter in colour and brighter in fracture than that in No. I. In No. I. nitro-hydrochloric acid was used in the determination of the silicon, and in No. II. the powder was fused in a platinum crucible with a mixture composed of 1 part of chlorate of potash, and 4 parts of the mixed carbonates of potash and soda. From the metal in both experiments the hydrogen liberated by the action of hydrochloric acid had an offensive odour like that from ordinary varieties of iron, and which is generally attributed to the presence of carbon.

The following experiments[7] have been made in my laboratory with compact hard red hæmatite, containing much finely diffused quartz. Hydrochloric acid by digestion with this ore left 13·49 % of insoluble residue, of which 12·76 % consisted of silica.

1. Heated in admixture with about sufficient charcoal to reduce it, it yielded metal containing 0·87 % silicon.

2. The same ore heated in admixture with a considerable excess of charcoal yielded metal containing 13·78 % of silicon. In both these experiments the crucibles were exposed to a very high temperature. In another experiment this ore was heated with charcoal and sand in excess, when the button contained 8·84 % of silicon.

This silicious ore was reduced by charcoal in the presence of various matters. In each experiment 1000 grains of ore were employed, and an intimate mixture of all the ingredients was made by trituration in a mortar. The numbers represent grains.

3. Charcoal 250, lime 100, fluor-spar 250. The metal produced contained 1·41% of silicon.

4. Charcoal 250, fluor-spar 150. The metal contained 2·15 % of silicon.

5. Charcoal 250, lime 400, clay 190, sand 110. The calculated percentage composition of the slag is—lime 51, alumina 10, silica 39. The metal contained 0·64 % of silicon.

6. Charcoal 250, lime 300, clay 190, sand 190. The calculated percentage composition of the slag is—lime 52·4, alumina 13·3, silica 34·3. The metal contained 0·58 % of silicon. The slags resulting from these mixtures approximate in composition to ordinary "blast-furnace cinders," *i.e.*, slags from iron-smelting furnaces in this country.

7. Charcoal 350, lime 125, clay 190, sand 260. The metal was "white iron," and contained 0·85 % of silicon. Reduction was not complete.

8. Charcoal 250, lime 125, clay 190, sand 260. The calculated percentage composition of the slag is—lime 19, alumina 11·5, silica 69·5. The metal contained 0·38 % of silicon.

9. Charcoal 250, lime 125, clay 190, sand 400. Additional charcoal was placed on the top of the mixture. The slag was green. The metal contained 1·15 % of silicon.

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[7] The experiments were made by Mr. Smith, and the quantitative determinations by Mr. W. Weston.

Another variety of red hæmatite greasy to the touch was operated on; it contained 6·36 % of matter insoluble in hydrochloric acid, and of this only 1·57 was silica.

10. This ore heated with excess of charcoal yielded metal containing 1·66 % of silicon.

11. This same ore mixed with fine sand and heated with excess of charcoal yielded metal containing 5·15 % of silicon.

The silicious ore employed in these experiments when smelted in the blast-furnace yielded pig-iron containing 4·2 % of silicon.

It must be particularly borne in mind that in the small experiments, of which the results are above recorded, the matters added were intimately mixed with the ore; but it is not possible to realize this condition economically on the large scale, except perhaps in some very exceptional cases, as for example, where the ore is levigated, allowed to subside and consolidate, then made into brick-like pieces, which are dried and burnt. The ore from the Cornelia Mine, near Stolberg, is thus treated. It is an earthy brown hæmatite, consisting of small compact angular lumps, varying in size from a walnut to a pea, and of much ore dust. The presence of this dust would render the ore unfit for smelting.[8]

The physical characters of the other silicides of iron, which I have examined, and which contain carbon, are as follow:—

With 13·78 % of silicon, the product of No. 2 experiment, above recorded. The button was somewhat honeycombed on the upper surface, the cavities containing bright graphite-like scales. It was hard and easily broken across. The fractured surface presented several cavities, especially towards the bottom, and these were lined with bright graphite-like scales. The other parts of the fracture were scaly crystalline, bright, and of a yellowish iron-grey tint, contrasting well with the apparently graphitic portion.

With 8·84 % of silicon, obtained in another experiment under No. 2. The button was quite smooth on the upper surface, which was convex and rounded at the edges. It was hard, and broke easily across, and the fractured surface was free from cavities. It was crystalline, somewhat dull in lustre, and of a dark yellowish grey.

With 5·15 % of silicon, obtained in No. 11 experiment. The button was well melted, convex on the upper surface, and rounded off at the edges. It was hard and brittle. The fracture was uneven, granular, dark grey, and remarkably devoid of lustre.

It is well worthy of attention that buttons of such different external characters should thus have been procured under conditions apparently so similar.

Pig-iron, containing 3 % of silicon, has invariably a smooth face; whereas cold-blast iron, containing from 1 % to 2 % of silicon, has a "honeycombed face," as it is technically termed. Mr. Parry is my authority for these statements.

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[8] Official Catalogue of the Mining and Metallurgical Products; Class I. in the Zollverein Department of the International Exhibition, 1862, p. 36. Nos. 621, 622.

With 7·46 % of silicon. I received this specimen from Mr. E. Riley. It was made many years ago at the Dowlais Iron-works from a very weak black band, and it is not stated whether by hot or cold blast. It is reported to be very liquid when melted. It was hard and brittle. The fracture was granular and imperfectly crystalline. The colour was light grey with a yellowish tinge, and in lustre and texture it might have been mistaken for bell-metal.

With 8·2 % of silicon. This specimen was communicated to me by my friend Mr. Abel, of the Arsenal, Woolwich. The fracture was crystalline, somewhat lamellar, with distinct cleavage planes set at various angles, so that, on turning the piece about, these planes come successively in view; they were not bright, but dull and finely granular; the colour was light grey for pig-iron. It contained per cent. :—

Carbon, entirely as graphite	2·63
Silicon	8·20
Phosphorus	0·70
Sulphur	0·02
Manganese	0·02

Berzelius states that he had a specimen of silicide of iron, which by solution in hydrochloric acid yielded 19 % of silica; that is, was very soft, and could be hammered out cold into thin plates. This does not agree with my observations. The same chemist also remarks that silicide of iron is not changed by exposure to the air, provided the silicon does not exceed 5 % or 6 %.[*]

Silicide of iron heated with phosphide of iron.—The following experiment was made by Mr. Hochstätter in my laboratory :—Of silicide of iron, containing 8·96 % of silicon, 220 grains were mixed by trituration with 143 grains of phosphide of iron containing 12·66 % of phosphorus. The mixture was heated in a covered clay crucible, placed within another, during 1 hour to whiteness. A well-melted button was procured, weighing 356 grains, and covered at the top with a little slag. It was very hard, very brittle, and strongly magnetic. Its fracture was largely crystalline, but the planes of cleavage were uneven, finely granular, and not bright; its colour was light-greyish white. The powder of the button, on digestion with hot hydrochloric acid, evolved hydrogen, of which the odour resembled that of hydrogen from ordinary iron, and not in the least degree that of phosphuretted hydrogen. By analysis the metal was found to contain 5·57 % of silicon, and 4·50 % of phosphorus. If no phosphorus had been expelled, it should have contained 5 % of phosphorus.

Silicide of iron heated with protosulphide of iron.—The following experiment has been made by Mr. Hochstätter :—Of protosulphide of iron, containing 60·63 % of iron, 200 grains were intimately mixed by trituration with 200 grains of silicide of iron containing 8·96 % of silicon. The mixture was heated to whiteness during 1 hour in a covered clay crucible. The product weighed 390 grains, and consisted of two distinct layers: the lower one resembled, in all respects,

[*] Tr 2, p. 704.

the original silicide of iron, weighed 160 grains, and contained only a little sulphur; the upper one resembled, in all respects, the original sulphide of iron, and weighed 230 grains, and in it were diffused some globules of the silicide. Hence it may be inferred that sulphide and silicide of iron have no action on each other at a high temperature.

Protoxide of iron and silica.—They readily combine at a temperature approaching a white heat; and, in certain proportions, form very fusible, and, when melted, very liquid compounds. The experiments of Berthier on this subject will be found in the table of silicates in the First Part of the 'Metallurgy.' It is essential that these silicates should be very carefully studied with special reference to the smelting and manufacture of iron. Earthen crucibles cannot be employed in their preparation, as they are rapidly corroded by oxide of iron, as well as silicate.

The following experiments have been made in my laboratory by my pupil, Mr. Richardson.

The silicates were prepared by strongly heating intimate mixtures of silica in the state of white sand with the purest red hæmatite and powder of anthracite in sufficient proportion to reduce it to protoxide. Wrought-iron crucibles were employed, enclosed in covered crucibles of graphite.

FeO, SiO^3.

	Ratio of mixture to yield 100 of the silicate.
Hæmatite	47·1
Silica	57·5
Anthracite	6·0

The temperature was nearly that of whiteness, as the iron crucible burned with sparks when taken out of the furnace. The product was very thick, and quickly solidified, so that in pouring it into an iron ingot-mould much remained adherent to the mouth of the crucible. When solid it was highly vesicular, dark olive-brown in colour, opaque, brittle, vitreous, and uneven in fracture. The powder was brownish grey, and not attracted by the magnet. By digestion with hydrochloric acid it was completely decomposed, with the separation of gelatinous silica, which dissolved without residue in a boiling solution of carbonate of soda. It was found to contain 33 % of iron, the theoretical amount being 33·05 % ($SiO^3 = 46$). The experiment was repeated with precisely the same results.

$3FeO, SiO^3$.

	Weights used in grains.	Ratio of mixture to yield 100 of the silicate.
Hæmatite	2400	78·1
Silica	900	29·8
Anthracite	180	6·0

The product was very liquid, and could be easily and completely poured out of the crucible. It required a considerable time to become perfectly solid throughout. It weighed 3070 grs., thus showing an excess of 70 grs. due to iron derived from the crucible. It had a bright, almost metallic lustre, was brittle, and highly crystalline, and on fracture several cavities were disclosed at the upper part, which contained beautiful crystals of iron olivine, resembling those frequently

produced in the conversion of cast into malleable iron. The fracture of the compact portion at the bottom of the button was largely crystalline, presenting cleavage planes disposed perpendicularly to the external surface. The powder of this silicate was black, and was not attracted in the least degree by the magnet. It was completely decomposed by digestion with hydrochloric acid, yielding gelatinous silica soluble without residue in a boiling solution of carbonate of soda. It contained 54 % of iron, the theoretical amount being 54·5 %. This experiment was repeated several times with the same results. In the following experiment anthracite was omitted :—

	Weights used in grains.	Ratio of mixture to yield 100 of the silicate.
Hæmatite	800	78·1
Silica	290	29·8

The product resembled in all respects those obtained in the preceding experiments, but weighed 1384 grs., thus showing an excess of 384 grs. due to iron from the crucible, which was much corroded where in contact with the silicate. The iron so removed was doubtless oxidized at the expense of that portion of the oxygen of the sesquioxide with which anthracite would have combined. This product was found to contain 51·52 % of iron.

The tribasic silicate of protoxide, prepared in the manner described, was fused with sufficient hæmatite and anthracite to yield respectively one, two, and three additional equivalents of protoxide of iron; but in every case the product consisted of a well-melted silicate which could be easily poured out, and proved to be the tribasic silicate unchanged, a sintered mass remaining which was strongly attracted by the magnet.

This is the silicate which may frequently be obtained well crystallized at forges, and to which I have previously directed attention.[1] It belongs to the right prismatic system. Its hardness is 6 (felspar), and its specific gravity at 18° 6 C. is 4·0805. It should, however, be stated that these observations were made, by my friend Professor Miller of Cambridge, on a specimen of slag found in the flue of a puddling-furnace, and not, as will be seen from the following analysis by myself, on the silicate in a state of absolute purity :—

Silica	29·60
Protoxide of iron	48·43
Sesquioxide of iron	17·11
Protoxide of manganese	1·13
Alumina	1·28
Lime	0·47
Magnesia	0·35
Phosphoric acid	1·34
Sulphide of iron (FeS)	1·61
	101·32

The sesquioxide of iron present appears to have been formed by the peroxidation of protoxide subsequent to the formation of the crystals.[2]

[1] Metallurgy, First Part, p. 23.

[2] Vid. Metallurgy, First Part, loc. cit.

Estimating the whole of the iron as protoxide, the formula is clearly that of $3FeO, SiO^3$.

On attempting to make silicates of the formulæ $3FeO, 2SiO^3$, and $6FeO, SiO^3$, by the method adopted in the preceding experiments, it was always found that the silicate poured out of the crucible contained the same proportion of protoxide of iron as in tribasic silicate, and in all respects resembled this silicate, and that a sintered, unfused mass of oxide of iron, attractable by the magnet, remained. When silicate of protoxide of iron, containing more silica than tribasic silicate, was heated in an iron crucible, the latter was energetically attacked and corroded; and this action ceased only when sufficient protoxide had been produced to form tribasic silicate. This fact, as will be seen hereafter, is of great practical importance in reference to certain processes in the manufacture of iron. The statements immediately preceding are founded on the following experimental evidence:—

$3FeO, 2SiO^3$.

	Weights used in grains.	Ratio of mixture to yield 100 of the silicate.
Hæmatite	580	58·2
Silica	470	47·5
Anthracite	42	6

The product resembled the tribasic silicate. It weighed 1508 grs., and contained 50·06 % of iron. The crucible was eaten away.

The experiment was repeated with the same weight. The crucible was much corroded. The product weighed 1570 grs. Supposing the sesquioxide of iron to be simply reduced to protoxide with the liberation of oxygen ($Fe^2O^3 = 2FeO + O$), the product should weigh 992 grs.; but supposing the sesquioxide to be reduced by the iron of the crucible, with the formation of an equivalent proportion of protoxide of iron, and this to combine with silica, then the product should weigh 1253 grs. Again, if sufficient iron of the crucible be oxidized to convert the whole of the silicate into tribasic silicate, the product should weigh 1574. The weight actually found was 1570; but this close approximation is probably accidental, as in experiments of this nature it is not to be expected that very accurate results should be obtained.

On the reduction of silicate of protoxide of iron by carbon.—The following investigations on this subject have been made in my laboratory by my pupil Mr. Richardson. Clay crucibles, brasqued with a mixture of charcoal-powder and treacle, were employed. The slag called *tap-cinder*, from a puddling-furnace, was first operated upon. It yielded by wet assay 55·19 % of iron, an amount which slightly exceeds the theoretical proportion in tribasic silicate ($3FeO, SiO^3$). Of the powder of this slag 10 grs. were intimately mixed with 2 of charcoal, and exposed in a luted brasque, during an hour, to a strong heat in an assay-furnace. The results of two similar experiments are stated underneath. Well-melted buttons of very brittle *white iron*, and a little greenish-yellow slag, were obtained. Tap-cinder usually contains much phosphoric acid, which would make the reduced iron rich in phosphorus, and consequently brittle:—

	1. Weight in grains.	2. Weight in grains.
Iron	5·35 or 53·5 %	5·34 or 53·4 %
Slag	1·48 or 14·8 %	1·56 or 15·6 %

Tribasic silicate of protoxide of iron was expressly prepared by heating together, in intimate admixture, very pure hæmatite, fine white sand, and anthracite, in proportions calculated to yield this silicate. The actual quantities employed were, in grains, hæmatite 2400, sand 900, and anthracite 200. The mixture was heated in a wrought-iron crucible in an assay-furnace, and combination took place somewhat suddenly at a temperature nearly approaching whiteness. The product, which was very liquid, was poured into an iron ingot-mould. It was broken when cold; its fracture was highly crystalline; and in a cavity near the surface were well-defined crystals, having the characters proper to the tribasic silicate, deep greenish-black in colour, vitreous in lustre, translucent at the edges, etc. It weighed 3070 grs., and yielded by wet assay 52·9 % of iron, the theoretical per-centage being 53·6 %.

I. 100 grs. of this silicate in fine powder were put without any addition into a brasqued crucible fitted with a charcoal plug and well luted cover, and subjected during 1½ hour to the strongest heat of an assay furnace capable of melting wrought-iron. The product was a mass of light olive-grey slag, containing small disseminated globules of iron and one large button, which was white, highly crystalline on fracture, and yet *very malleable*, unlike that obtained from tap-cinder, which is an *impure* tribasic silicate. The button weighed 33·92 grs. and the globules 2·36 grs., the total iron reduced being 36·28 %. It will be observed that it was not in the state of *cast-iron*.

	2. Weight in grains.	3. Weight in grains.	4. Weight in grains.
Tribasic silicate	100	100	100
Large button of iron	24·94	29·58	31·34
Globules of iron	11·04	4·50	3·37
Total iron	35·98	34·08	34·71

In No. 3 the residual slag was weighed: it amounted to 56 grs.

5. 1000 grs. of the tribasic silicate were treated as in the preceding experiments: the product was a hollow spherical mass of reduced iron, intermixed with slag, which penetrated the brasque in veins, was very tough and darkish grey. The temperature had not been high enough, as will appear from the result of the next experiment.

6. 800 grs. of the tribasic silicate were very strongly heated during 3 hours, and the result was similar to those of the first experiments. The large button weighed 214·38 grs. and the globules 64·58, the total iron reduced being 278·96 grs., or 34·87 %. The large button was very malleable and largely crystalline on fracture.

In the preceding experiments the average percentage of iron reduced was 35·18 %. A portion of the residual silicate or slag obtained in

one of these experiments was fused with a mixture of carbonate of soda and potash, the product treated with hydrochloric acid, the silica separated in the usual manner, and the iron determined by standard solution; the proportion was 33·9 %, which corresponds to the formula FeO, SiO^3. Hence, only two of the equivalents of protoxide of iron in tribasic silicate can be reduced by carbon.

Silicate of sesquioxide of iron.—On attempting to make silicates of the formulæ $Fe^2O^3, 3SiO^3$, the weights employed were 370 grs. of hæmatite and 640 grs. of sand. On pouring from the crucible only a small portion flowed out, which weighed 195 grs., resembled tribasic silicate of protoxide of iron in appearance, and contained 50 % of iron. A sintered greyish black mass, weighing 1011 grs., was left in the crucible; about half of it was magnetic oxide of iron, the other half being uncombined silica.

Tribasic silicate of protoxide of iron heated with access of air.—When the powder of this silicate is roasted with access of air at a good red heat, oxygen is absorbed and the protoxide of iron passes in a greater or less degree into sesquioxide. When the silicate is also similarly roasted in pieces, even as large or larger than the fist, the same change occurs; and if the process is continued during a sufficient time, a comparatively infusible product is obtained. A very large quantity of this silicate or "tap-cinder," which is formed in the manufacture of iron, is roasted during several days in kilns, exactly resembling common brick-kilns. Oxidation takes place, and the refractory substance called "bull-dog" is the result. This process was patented by Messrs. Bradley, Barrows, and Hall, of Tipton, South Staffordshire, in 1838.[3] Bull-dog has a bright lustre, strongly inclining to metallic, is dark grey in colour, and has frequently a beautiful velvety appearance on the surface. The infusibility entirely depends on the peroxidation of the iron. The late Mr. T. H. Henry informed me that he had analysed specimens of bull-dog in which the iron existed wholly as sesquioxide; and as the silica separated from it by hydrochloric acid was in a *pulverulent*, and not in a gelatinous, state, he inferred that it did not exist in combination with the sesquioxide of iron. I believe this view to be correct; for, on strongly heating intimate mixtures of sesquioxide of iron under conditions in which no reducing agent was present, we have failed to obtain any evidence of combination.

Liquation of silicate of protoxide of iron containing phosphorus.—The tap-cinder or slag from which bull-dog is made frequently contains a large amount of phosphorus, which is chiefly, though it may not be wholly, in the state of phosphoric acid. During the operation of roasting some of the slag runs out melted through the fire-holes, while another portion known as "bull-dog slag" runs down and forms a continuous bed over the bottom of the kiln. This slag appears to result, in part at least, from a process of true liquation; and evidence in favour of this view is derived from the following analyses by the late Mr. T. H. Henry. The portions operated upon were selected with

[3] No. 7778. A.D. August 21, 1838.

care from the same kiln by Mr. S. H. Blackwell, and may be considered as having been fair samples. After the liquation had taken place, peroxidation of the iron occurred.

	1.	2.	3.
Sesquioxide of iron	72·60	51·43	54·64
Silica	17·21	27·05	22·00
Oxide of manganese (Mn^3O^4?)	4·21	11·15	8·98
Lime; alumina	traces	0·40	0·00
Phosphoric acid	5·43	9·60	13·87
	99·45	99·63	99·49

No. 1 was the bull-dog itself; No. 2, bull-dog slag; No. 3, slag which had run out through the fire-holes. The difference in phosphoric acid is very striking. It might almost be supposed that a considerable part of the phosphorus had existed in the original slag as phosphide of iron, and had simply liquated, owing to its ready fusibility. The difference in the manganese is also not less remarkable.

IRON AND BORON.

Protoxide of iron and boracic acid.—The following experiments were made by Mr. Richardson in my laboratory:—The substances employed were dried sulphate of protoxide of iron and fused boracic acid. The mixtures were heated in small Cornish crucibles, and the products were poured into an iron ingot-mould.

FeO, BO^3.

The proportions were 106·94 grs. of sulphate, and 49·23 grs. of boracic acid, which should have yielded exactly 100 grs. of borate of protoxide of iron. Fusion took place readily at a bright red heat; the molten product was very liquid; it was poured out into an iron ingot-mould; when solid it was covered superficially with a thin film of a bright-red colour; it was black, and vitreous in structure; and its powder was brownish black. It contained 37·50 % of iron, the theoretical proportion being 39·43 %.

Other similar experiments were made with a view to produce borates of the formulæ $3FeO, BO^3$,—$3FeO, 2BO^3$,—and $6FeO, BO^3$, when brownish black vitreous products of very variable composition were obtained.

Sesquioxide of iron and boracic acid.—The two following experiments were also made by Mr. Richardson. Hæmatite and fused boracic acid were the materials used.

Fe^2O^3, BO^3.

The proportions taken were hæmatite 69·56 grs., and boracic acid 30·43 grs. A rather high temperature was required to effect fusion. The product was coated superficially with a bright-red film; it was vitreous, and brownish-black. The sesquioxide of iron was found for the most part to be converted into protoxide.

$Fe^2O^3, 3BO^3$.

The proportions taken were hæmatite 43·24 grs., and boracic acid 56·76 grs. The product, which required a rather high temperature

for fusion, was in two distinct layers: the upper one was greenish-brown, and vitreous in fracture; and the under one was black, stony in fracture, and yielded a brownish-black powder. Both layers were perfectly non-crystalline, and contained iron chiefly in the state of protoxide. The upper layer contained 9 % of iron, and the under one 25·77 %. The experiment was repeated with similar results.

Iron and Carbon.

Of all the compounds of iron, none are to be compared with those of carbon in practical importance; and, in a scientific point of view, none possess greater interest. The influence of this element in causing variation in the physical properties of iron is one of the most extraordinary phenomena in the whole range of metallurgy. Under the common name of iron are included virtually distinct metals, which in external characters differ far more from each other than many chemically distinct metals. Without carbon the manifold uses of iron would be greatly restricted; and, so far as is yet known, no other metal or mixtures of metals could be applied to these uses. When carbon is absent, or only present in very small quantity, we have *wrought iron*, which is comparatively soft, malleable, ductile, weldable, easily forgeable, and very tenacious, but not fusible except at temperatures rarely attainable in furnaces, and not susceptible of tempering like steel; when present in certain proportions, the limits of which cannot be exactly prescribed, we have the various kinds of *steel*, which are highly elastic, malleable, ductile, forgeable, weldable, and capable of receiving very different degrees of hardness by tempering, even so as to cut wrought-iron with facility, and fusible in furnaces; and, lastly, when present in greater proportion than in steel, we have *cast-iron*, which is hard, comparatively brittle and readily fusible, but not forgeable or weldable. The differences between these three well-known sorts of iron essentially depend upon differences in the proportion of carbon, though, as we shall learn hereafter, other elements may and often do concur in modifying, in a striking degree, the qualities of this wonderful metal. Ours is emphatically the iron age; and it may be confidently asserted that no other element has contributed so largely to the civilization and happiness, and, may we not also add, paradoxical as it may seem, to the misery of mankind. But let us not forget that carbon has done its share in this good and evil work.

Modes of effecting the combination of carbon with iron.—The essential condition of this combination is, contact of iron at, or above, a red heat with carbon, or with certain gaseous compounds of carbon. When an oxide of iron is reduced in admixture with *excess* of carbon, at or above the melting-point of cast-iron, combination takes place rapidly and cast-iron is produced; and, *cæteris paribus*, the higher the temperature, the more readily does this result occur. But combination is also effected, though much more slowly, when iron in the compact state of bar imbedded in charcoal powder is exposed to any temperature at or above redness. In this way steel is very largely made in England;

and the process is known by the name of *cementation*. The temperature usually employed for the purpose is stated to be about that of the melting-point of copper, or somewhat higher. A gaseous hydrocarbon may be substituted for solid charcoal; and this principle has also been applied in practice.

The process of cementation in a scientific, as well as practical, point of view, has a high degree of interest. Leplay regarded it at one time as "an unexplained mysterious operation," which he attempted to prove was exclusively due to the action of carbonic oxide. The oxygen of the air originally interposed amongst the particles of carbon is converted, first into carbonic acid, and then into carbonic oxide, which, in contact with iron, delivers up to the latter half of its carbon, and passes to the state of carbonic acid. But this acid is again immediately reduced by the carbon present to carbonic oxide, and so the iron becomes carburized through the direct agency of carbonic oxide. Gay-Lussac published a paper upon Leplay's views, from which I present the following extracts:[4]—

"What do we understand by this word 'cementation'? It is a word invented to indicate an unknown cause, an inexplicable effect; to indicate an anomaly, the only one of its kind presented in chemistry. . . . . MM. Leplay and Laurent have, it is true, upset this theory of carburization, in acknowledging subsequently that iron did not decompose carbonic oxide; but new experiments, peculiar to M. Laurent, have led him to admit that carbon was reduced to vapour at a very high temperature, and the carburization of iron was due to this vapour, and not in any degree to carbon in the solid state. . . . . Such, then, is the novel theory of M. Leplay, adopted also by M. Laurent, of the reduction of metallic oxides by carbon, and of carburization by cementation. These two operations are both due to the oxide or the vapour of carbon; and as they are very clear, very comprehensible by the intervention of these two elastic fluids, and are conformable to the principle of the ancients, *corpora non agunt nisi soluta*; the action of carbon, as a solid body, ought to be null, because, not being understood, it is mysterious. But how many phenomena are to us still surrounded with the deepest mystery! To deny them, would that be to explain them? MM. Leplay and Laurent, in proving that the oxide and vapour of carbon can reduce oxides and carburize metals, should have also proved that carbon is powerless, as a solid body, to produce the same effects; explanations, so easy to find, should have come afterwards. . . . . MM. Leplay and Laurent, in order to explain cementation and carburization by simple contact, which, for them, are obscure and mysterious operations, invoke the vaporous state of carbon, and believe they have solved all the difficulties of the question; but cementation, or the propagation of a chemical effect through the mass of a solid body, takes place quite as well by the addition, as by the subtraction, of matter; and if, in this latter case, the matter subtracted, like oxygen from an

[4] Ann. de Chim. et de Phys. 3 s. 17, p. 221, 1846. This paper was quoted in the First Part of "Metallurgy," under the head of Reduction.

oxide, catually leaves pores accessible to an elastic fluid, such as hydrogen or carbonic oxide, it is not the same in cementation with the addition of matter, as in the carburization of iron, where the metal preserves all its impermeability. In admitting, then, that the vapour of carbon has deposited a first layer of carbon at the surface of the iron, and that combination has taken place, how will carburization be propagated in the interior of the mass, inaccessible to vapour of carbon, and in what will it differ from that which will be effected by the simple contact of carbon? In fine, in what will it be less mysterious? Assuredly, cementation, taken in its whole extent, is not yet sufficiently explained, but we may maintain that it is entirely independent of the fluidity of the cementing body; for, as soon as we admit that the fluid may penetrate into the pores of the solid body and there exert its action, there is no longer, properly speaking, cementation or propagation of a chemical action through its mass, there is simply action by way of contact or of mixture. . . . . That cementation may be an obscure and mysterious operation, as MM. Leplay and Laurent think, we will not deny; but on the other hand we will not admit it to the extent of being forced, in order to explain it, to forget the clearest proofs admitted in chemistry. Cementation may be conceived when bodies in presence of each other act in indefinite proportions, like carbon with respect to iron; but, when they have reached the mono-atomic state, the partition from one layer to the other presents grave difficulties. . . . . Although I do not think, with these distinguished savans, that cementation is a mysterious operation, inaccessible to chemists and physicists, I admit that it requires to be better studied than hitherto, and I have the conviction that our efforts would not be in vain. In conclusion, I add, that it is no longer permitted to have blind faith in a principle so vulgarly (*banalement*) repeated of the ancient chemists, *corpora non agunt nisi soluta*. It is certain, on the contrary, that all bodies—solid, liquid, or aëriform—act upon each other, but that, of the three states of bodies, the solid state is the least favourable to exercise of chemical affinity."

The language employed by Gay-Lussac may, perhaps, be considered as somewhat caustic; but his reasoning, to my mind, appears clear and convincing. France has never produced a more truth-loving and more philosophic chemist than Gay-Lussac; and his entire freedom from ostentatious display and personal vanity made an indelibel impression upon my mind when I attended his lectures thirty years ago at the Jardin des Plantes. I do not remember to have heard him even once mention his own name when speaking of his own discoveries; and, in this respect, he contrasted remarkably with his illustrious colleague, Baron Thénard. Both are in their graves, and both have bequeathed to France a legacy of fame, of which she may well be proud. Poor Laurent, also, is dead, and he did excellent work. Leplay survives, and is in the enjoyment of wealth and political dignity.

I have now to record a series of experiments which I have made on the carburization of iron by cementation, and which, though very

far from complete, yet may, probably, be found to possess some points of interest. I hoped long before this to have carried on the investigation, but as I know not when I shall be able to do so, and as life is at all times uncertain, I venture to publish the results, such as they are. In these experiments I have been assisted by Mr. C. Tookey.

Action of carbonic oxide upon iron.—The gas was prepared by heating sulphuric acid with ferrocyanide of potassium (Fownes' method), and collected in a water gasometer, from which it was passed through two tubes, each 34 inches long, filled with chloride of calcium; then through a succession of four tubes, each also 34 inches long, filled with fragments of potash; and at last through a porcelain tube placed over a long gas combustion furnace with numerous clay burners, such as is now commonly employed in ultimate organic analyses. On leaving the porcelain tube, it passed through a weighed apparatus containing solution of caustic potash, and having a short tube filled with fragments of potash from which it escaped into the air.

1. Narrow strips of commercial thin sheet-iron of very fine quality were employed, their surfaces having first been cleaned with hydrochloric acid, rapidly washed with water, immediately afterwards wiped dry, and gently heated. These were placed in the porcelain tube, and a current of carbonic oxide was sent through the apparatus until there was reason to believe that atmospheric air had been completely expelled. Two similar strips of iron were operated on. Each was $\frac{3}{4}$ in. broad and 8 in. long; together they weighed 28·96 grains. That part of the porcelain tube where the strips lay was then heated to bright redness, and kept at that temperature during the whole course of the experiment, which lasted 3 hours, carbonic oxide passing through all the while. In all 70 cubic inches of gas, measured moist, left the gasometer. The tube was allowed to cool slowly, and when perfectly cold the iron was taken out. The strips weighed 28·97 grains; so that there was an increase of 0·01 grain, or 0·034 %. The potash apparatus increased in weight 0·62 grain. The experiment was afterwards resumed with the same strips of iron; but the gas, as it left the gasometer, was sent through a solution of caustic potash in its way to the series of tubes above described. It was continued during 3 hours at the same temperature as before, during which time 15 cubic inches of gas left the gasometer. It is evident that there is an error somewhere; for, otherwise, supposing the increase in weight of the iron due to carbon, only 0·036 of carbonic acid should have been formed. It occurred to me as possible that a little air might have got into the porcelain tube during cooling and after stopping the current of gas, as the surface of the strips was shaded off from blue to yellow from each end towards the central part, which was bright and perfectly free from colour. However, the experiment clearly shows that if the increase in weight were due to carbon, the action of carbonic oxide upon the metal during 6 hours at a bright red-heat is very small.

Action of solid carbon upon iron.—Charcoal prepared from fine white sugar was used. The first experiment was vitiated by the evolution

of gaseous matter from the charcoal from imperfect carbonization. The charcoal was heated strongly in a gold crucible over an air-gas flame until no gas was seen to be evolved.

2. *In an atmosphere of carbonic oxide.*—A single strip of the same kind of iron, 8¼ in. long, was employed, and the same method of preparing it was adopted. It was bent so as to form an imperfect tube, and was imbedded in charcoal in the porcelain tube. It weighed 29·485 grains. A current of carbonic oxide was sent through the apparatus with the precautions above mentioned, and the tube was kept at a bright red-heat. The operation lasted 3 hours, during which time 100 cubic inches of gas left the gasometer. The potash apparatus increased in weight 1·53 grains, and the iron 0·295, or 0·990 %. The iron superficially was dark grey; it became brittle after heating to redness and cooling in mercury; it was steel.

3. *In an atmosphere of hydrogen.*—A single strip, ⅜ in. broad and 8¼ in. long; the same kind of iron was used. It was kept at a red heat during about 2 hours in a current of dry hydrogen, and allowed to cool in the gas. The surface was bright and light coloured. The same apparatus was used as in the preceding experiments, with the substitution of hydrogen for carbonic oxide. The gas was made from zinc and dilute sulphuric acid, and was first passed through a solution of caustic potash containing protoxide of lead dissolved. The strip was imbedded in sugar charcoal, as in the last experiment. Gas was sent through during the 3 hours, the porcelain tube being kept at a bright red heat all the while. The strip of iron was left to cool in the gas. It could only be hardened by heating to redness and plunging into mercury for about ⅔ of its length. It was at first supposed that it might not have been in contact with charcoal for ⅓ of its length. Before the experiment it weighed 15·81 grains, and afterwards 15·92, *i.e.* increased in weight 0·690 %.

4. Experiment 3 was exactly repeated. A single strip of iron was used, ⅝ in. broad and 7¾ in. long. It was thoroughly imbedded everywhere in the *same* charcoal as employed in the last experiment. Before the experiment the strip weighed 15·385 grains, and afterwards 15·550, *i.e.*, increased in weight 1·061 %.

5. Two strips of the same kind of iron as used in the preceding experiments, and prepared in the same manner, were used. One strip was imbedded in the *same* charcoal as employed in Expts. 3 and 4, while the other was not; they were kept separate by a plug of asbestos, and the free strip was put near the end of the porcelain-tube from which the gas escaped. Each strip was curved, so as to form half a cylinder. The experiment was continued during 3 hours, precisely as heretofore. Before the experiment, the free strip weighed 5·405 grains, and afterwards 5·425, *i.e.*, increased in weight 0·368 %; the imbedded strip before the experiment weighed 5·805 grains, and afterwards 5·850, *i.e.*, increased in weight 0·769 %. There was considerable difference in the appearance of the two strips; the surface of the free strip was dead in lustre, and somewhat resembled zinc in

colour; the surface of the imbedded strip was brighter, especially on the convex side, and of a deeper grey tint.

This result struck me as remarkable. Admitting the purity of the hydrogen employed, the gas must either have taken up carbon in its passage over the charcoal, or a gaseous compound of carbon must have been evolved from the charcoal, notwithstanding its long continued exposure to a bright red heat—for it was the *same* charcoal as used in previous experiments—or it is conceivable that some dust of charcoal might have been carried forward and come in contact with the strip of iron. There was, however, reason to believe that the last condition did not occur; and we shall presently learn that a precisely similar result was found, when it was absolutely certain that not a trace of charcoal had been carried over mechanically. It will also be shown that the hydrogen *per se* had no share in producing the effect in question.

6. This experiment was conducted, with the *same* charcoal, in the same manner as the last, except that the position of the two strips of iron was reversed, the free strip being first exposed to the incoming hydrogen. The strips were separated from each other by a plug of asbestos, and there was a considerable interval between them. Everything was arranged with the greatest care, so that no charcoal could get access to the free strip. The strips were introduced flat, and not bent. The experiment was continued during 3 hours as heretofore. The imbedded strip before the experiment weighed 8·00 grains, and afterwards 8·045, *i.e.*, increased in weight 0·559 %; the free strip weighed before the experiment 8·62 grains, and afterwards 8·615, so that there was a loss of 0·005; but I regard the difference in weight as an error of observation;—there was, however, certainly no increase, and that is the main point. The imbedded strip became as brittle as glass after plunging it while red-hot into mercury; whereas the other strip could be bent without breaking after the same treatment.

7. Again the *same* charcoal was used, but pounded finer: it was found to be very hard. A strip of the same kind of iron, prepared in the same manner, was imbedded in charcoal, and the experiment was continued during four hours, a current of hydrogen passing all the while. The strip before the experiment weighed 15·530 grains, and afterwards 15·675, *i.e.* it increased in weight 0·925 %. The surface of the strip was very bright; but at the end which was first exposed to the gas, it did not harden by plunging it while red-hot into mercury.

8. Experiment 5 was exactly repeated during four hours, the tube having been very carefully sponged out. The *same* carbon was again used. There were two free strips, which together before the experiment weighed 12·106 grains, and afterwards 12·150, *i.e.* it increased in weight 0·362 %; the imbedded strip, in one piece, before the experiment, weighed 6·808 grains, and afterwards 6·835, *i.e.* it increased in weight 0·395 %. The end which first came in contact with the gas did not harden by plunging it while red-hot into mercury, although it was believed to have been imbedded in carbon.

9. A long tube of Bohemian glass was employed instead of the

porcelain tube, and strips of electro-deposited iron were operated on. The following diagram represents the arrangement.

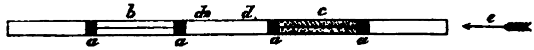

Fig. 1.

a, *a*, *a*, *a*, asbestos plugs; *b*, free strip; *c*, imbedded strip; *d*, *d*, void space 10 inches long, perfectly clean; *e*, arrow, showing direction of the gas.

The *same* carbon, which had been repeatedly used, was employed. In all respects the arrangements were the same as heretofore. The experiment lasted four hours, and afterwards not the slightest deposit could be perceived in the void space *d d*. The free strip, *b*, before the experiment, weighed 5·955 grains, and afterwards 5·970, *i.e.* it increased in weight 0·251 %; the imbedded strip before the experiment weighed 5·550 grains, and afterwards 5·622, *i.e.* it increased in weight 1·280 %. Both strips readily hardened by plunging red-hot into mercury. This increase is remarkable, and may have depended to a certain extent upon the molecular, and possibly loosely aggregated state of the electro-deposited metal.

10. In this experiment two long glass tubes were employed, as shown in the following diagram:

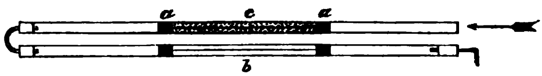

Fig. 2.

b, the free strip; *c*, the imbedded strip. The *same* charcoal as used in the foregoing experiments was employed. The operation lasted three and a half hours. Thin sheet, but not electrotype, iron was employed. Before the experiment the free strip weighed 9·458 grains, and afterwards 9·468, *i.e.* it increased in weight 0·105 %; the imbedded strip before the experiment weighed 10·081 grains, and afterwards 10·133, *i.e.* it increased in weight 0·513 %. Not the slightest dust was carried over into the second tube.

11. Experiment 9 was exactly repeated during four hours, except that the hydrogen was passed first through a solution of nitrate of silver in water, and then through pumice wetted with strong sulphuric acid. Electrotype iron was used. The free strips—there were two—before the experiment weighed 9·086 grains, and afterwards 9·150, *i.e.* they increased in weight 0·699 %; the imbedded strip before the experiment weighed 5·026 grains, and afterwards 5·080, *i.e.* it increased in weight 1·062 %.

12. Experiment 9 was repeated during four hours, with charcoal powder which had been washed with hydrochloric acid, etc.; and thin sheet iron, not electro deposited, such as at first employed, was operated on. The free strip before the experiment weighed 7·805 grains, and afterwards 7·815, *i.e.* it increased in weight

0·127 %; the imbedded strip before the experiment weighed 7·270 grains, and afterwards 7·284, *i.e.* it increased in weight 0·192 %. Both strips were sensibly hardened by plunging while red-hot into mercury.

13. The same apparatus was employed with hydrogen, etc. A strip of iron, not electrotype, was imbedded in wood-charcoal, in small particles freed from dust by sifting, and previously heated in a covered crucible during several hours at a high temperature in an assay furnace, with anthracite as the fuel. Before the experiment, the strip weighed 13·293 grains, and afterwards 13·300, *i.e.* it increased in weight 0·0526 %. It did not harden by plunging while red-hot into mercury.

14. Experiment 13 was repeated in precisely the same way in all respects. The strip before the experiment weighed 10·465 grains, and afterwards 10·469, *i.e.* it increased in weight 0·0382. It did not harden by the usual treatment.

15. Some of the sugar charcoal which had *not* been used was exposed during four or five hours in a covered crucible to the highest temperature of an assay furnace, heated with anthracite, and in which wrought-iron could be melted without diffictuly. Thin sheet, not electrotype, iron was imbedded in this charcoal, and heated during three and a half hours as heretofore in a current of hydrogen. Before the experiment it weighed 12·166 grains, and afterwards the weight remained the same.

16. When iron wire is kept at a red heat during only an hour in coal-gas, it hardens exactly like steel. This is a very pretty and striking lecture experiment, which I have often made.

17. The vapour of paraffine may be conveniently substituted for coal gas. The experiment was made in my laboratory by Mr. Hochstätter of exposing iron wire to the vapour of this substance in a porcelain tube nearly to whiteness during an hour, when steel was formed.

The point of chief interest in the foregoing experiments is the carburization of iron in hydrogen, which has passed over charcoal heated to redness; and which, obviously, must have contained a gaseous compound of carbon. The questions suggested by this point are—did hydrogen under these conditions take up any carbon; or was the gaseous compound of carbon, which caused the carburization of the iron, simply evolved from the charcoal employed? So far as I know, all previous experience is opposed to the first view; yet, if we accept the second view, it is extraordinary that a hydrocarbon should continue to be evolved from the same charcoal, exposed day after day to a strong red heat. Still, it has been well established that charcoal retains hydrogen with great tenacity, even after having been strongly heated; and this fact would appear to favour the second view, especially when we remember that the sugar-charcoal ceased to produce the slightest carburization after it had been subjected to intense heat (see Exp. 15). Is it possible that a current of hydrogen may tend to promote the disengagement of a hydrocarbon from charcoal at lower temperatures than those at which it would otherwise be sensibly evolved?

However, the fact should be particularly noted, that the intensely heated charcoal no longer carburized iron even by contact. In any respect, the preceding results appear to me curious and interesting; but further experiments are required to clear away the difficulties which remain. Should it be hereafter proved, as I think is probable, that a hydrocarbon continues to be slowly evolved during a long time from charcoal kept at a red heat, or at a somewhat higher temperature, the reason of the addition of a certain proportion of fresh charcoal at every renewal of the process of making steel by cementation on the large scale will become intelligible. All charcoal used for this purpose contains a notable quantity of hydrogen, which at higher temperatures than that of carbonization on the large scale would be driven off partly in combination with carbon; and this compound would actively, though perhaps not exclusively, determine carburization.

The process of carburization by cementation, whether effected through the agency of a gaseous compound of carbon, or by the direct contact of solid carbon, is remarkable, and difficult of explanation. It is easy to understand how the outermost layer of the metal should become carburized, but not easy to understand why this should give up carbon to the layer immediately underneath, the second layer to the third, and so in succession; until the centre of a bar of iron, even though of considerable thickness, receives its full complement of this element; a continual addition of carbon from without, supplying the deficiency, as layer after layer in turn parts with carbon. If we admit that there is chemical combination, a point which will be presently examined, why should one layer yield up its carbon to another? If, on the other hand, the phenomenon is analogous to solution, it appears somewhat more intelligible; for, although the iron is not in a state of fusion, yet it is strongly heated, and its particles have thereby acquired a sensible degree of freedom of motion. In the reduction of a solid lump of oxide of iron in contact with red-hot carbon, carbonic oxide seems to be the essential agent; and, as Gay-Lussac has remarked, it is easy to conceive how this gas should find its way to the interior through innumerable fissures or pores. The abstraction of oxygen from the outermost layer of such a lump, at a temperature far below the welding point of iron, must of necessity render the contiguous layer pervious to the reducing gas, and so on in succession to the centre. But, in cementation by carbon, there is the difficulty above mentioned, which does not exist in this so-called reduction by cementation of a lump of oxide of iron. There is a veritable diffusion in the former of one solid through another, which suggests what occurs in liquid diffusion. While the fact is patent, the conception of the *modus operandi* is very obscure. We may easily bewilder ourselves with words, believing that we have found an explanation, when we have in reality done no more than express the phenomenon in other terms—a fallacy by no means uncommon in science as well as in other branches of knowledge.

Carbon may be extracted from, as well as introduced into, solid iron, by a process of cementation, which has long been practised.

Thus, when cast-iron is imbedded in the powder of red hæmatite, and kept at a bright red heat during two or three days, it loses carbon, acquires a considerable degree of malleability, and is converted into what is termed "malleable cast-iron." In England various small objects of cast-iron obtained by smelting red hæmatite with charcoal are treated in this manner. Dr. W. A. Miller has published the following analyses of the metal before and after the process:—

		Before.		After.
Specific gravity		7·684		7·718
		In 100 parts.		
Carbon	Combined ...... 2·217 Uncombined ... 0·583	2·800	0·434 0·446	0·880
Silicon		0·951		0·409
Aluminium		trace		trace
Sulphur		0·015		0·000
Phosphorus		trace		trace
Sand		0·502		——

Hence, about $\frac{4}{5}$ of the combined carbon appear to have removed; while the uncombined, or graphitic, carbon suffered scarcely any diminution. The abstraction of more than half the silicon seems very remarkable, and I cannot in the least understand it. I have spoken to Dr. Miller on the subject, and he assures me that there is no reason to question the accuracy of the result. Every trace of sulphur, which, it is well known, pertinaciously adheres to iron, was eliminated, which certainly could not have been anticipated. Carbon, as we shall hereafter learn more particularly, may be extracted in a greater or less degree from cast-iron by keeping the metal in the form of thin plates heated to redness, with access of air during a sufficient length of time. A process founded on this principle has also been applied; and Tunner asserts that silicon, as well as carbon, escapes.[5]

The amount of carbon in iron.—Of late years, owing to the progress of analytical chemistry, considerable attention has been given to the quantitative determination of carbon in iron; and although valuable additions have been made to our knowledge of this subject, yet, in my judgment, much remains for investigation, and I am not a little perplexed with many facts relating to it which are really elementary. Amongst the numerous observers who have taken up this line of inquiry, we are specially indebted to Karsten, the German, and Sefström, the Swede.

In 1846 Karsten communicated to the Academy of Sciences at Berlin a paper on the so-called "carburets of iron,"[6] and of this I now present an abstract. He considered that the maximum of carbon with which iron could combine was 5·93 %. At one time he believed that in every case a definite polycarbide of iron existed, which was simply dissolved in an excess of iron, and that upon the proportion of this carbide the quality of metal essentially depended. But he did not succeed either in preparing or separating such a carbide having

[5] Stabeisen u. Stahlbereitung, 2, notes, pp. 42–49.
[6] Über die Carburete des Eisens. Von Hrn. Karsten. Read Nov. 5, 1846.

a certainly definite composition. Pure iron, perfectly free from carbon, he writes, is so soft, that it offers but little resistance to friction; and is, therefore, unfitted for most of the purposes to which the ordinary metal is applied. When combined with carbon, not exceeding certain limits, iron increases in tenacity, and, consequently, in elasticity; as also in malleability, ductility, and hardness. The last property is increased by suddenly cooling after heating; and when it is considerable, as is the case in all iron containing more than from 0·2 % to 0·25 % of carbon, the metal is designated steel. The more free iron is from foreign matters, especially silicon, sulphur, and phosphorus, the larger is the amount of carbon required to induce hardening by this treatment. In the best Swedish bar-iron, as well as in bar-iron made in Germany from spathic and brown iron ores, 0·35 % of carbon suffices to communicate the property of hardening in a degree so considerable that such iron is properly termed "steely." The passage from this iron into steel is so gradual and insensible, that it is impossible to pronounce where one ends and the other begins. When, however, the carbon reaches 0·5 %, and other foreign matters are present in small quantity, iron is capable of being hardened sufficiently to give sparks with flint, and may then be regarded as steel. But in the caes of iron perfectly free from foreign matters, not less than 0·65 % of carbon is required to induce this property. Iron containing from 1·0 % to 1·5 % is steel, which, after hardening, acquires the maximum hardness combined with the maximum tenacity. When the carbon exceeds the highest of these limits, still greater hardness may be obtained, but only at the expense of tenacity and weldability. With 1·75 % of carbon, the last property is almost completely lost. With 1·8 % of carbon, iron may still with great difficulty be worked and drawn out under the hammer; and although very hard, it yet retains considerable tenacity. When the carbon rises to 1·9 % or more, the metal ceases to be malleable while hot; and 2 % of carbon appears to be the limit between steel and cast-iron, when the metal in the softened state can no longer be drawn out without cracking and breaking to pieces under the hammer.

Of cast-iron there are two distinct kinds, the grey and the white. They differ widely in colour, hardness, brittleness, tenacity, and fusibility. Grey iron has a higher melting-point than white iron, and in fusing passes almost instantly from the solid to the liquid state when it is very fluid; whereas white iron at lower temperatures becomes first soft and then pasty before melting. It was formerly supposed that these differences were due to the larger amount of carbon in grey than in white iron. Grey iron, by sudden solidification after fusion, becomes white; and white iron, by very slow solidification after fusion at a high temperature, becomes grey, without, in either case, any change in the proportion of carbon. [But I shall prove that this statement of Karsten's is not universally true.] It was, therefore, sought to explain these remarkable differences by corresponding differences in the mode of existence of carbon in these two kinds of iron. In white iron it was supposed that the carbon was wholly in combination

with the iron; and that in grey iron, it was partly in combination and partly diffused through the metal in the state of graphite. Iron containing 2·0% of carbon, *i.e.* steel, may, after fusion, followed by the slowest possible solidification, retain the whole of its carbon in combination; but when iron with 2·3% of carbon is thus treated, graphite separates, and the metal presents the characteristic appearance of cast-iron. Beyond this minimum limit the greater the proportion of carbon up to the maximum of 5·93%, the greater the whiteness and hardness of the iron when in the state of white iron. [But, according to my experience, iron can never retain anything like this amount of carbon in combination without the presence of a considerable quantity of manganese, which may, therefore, contribute to the development of both these properties.]

The maximum amount of carbon capable of being taken up by pure iron.—The following experiments on this subject have been made in my laboratory by Mr. Dick:—

Carbon was prepared by burning oil of turpentine or camphine, and collecting the lamp-black produced. Sesquioxide of iron was prepared by dissolving fine iron wire in hydrochloric acid, peroxidizing by nitric acid, precipitating by ammonia, washing, etc.; and some also was made by boiling sulphate of protoxide of iron with nitric acid, precipitating by ammonia, etc. Clay crucibles brasqued with camphine carbon were employed.

1. A mixture of sesquioxide of iron, made from the sesquichloride, with excess of carbon, was intensely heated. Several globules and a button of metal were obtained, and to the latter a minute quantity of slag was found attached. When the button was hammered it split without flattening. The fracture was dark grey, and tolerably uniform. The specific gravity of this button was 7·08. It was what would be properly designated highly graphitic iron. Two determinations of the iron which it contained were made by standard solution of bichromate of potash:—

1st gave of iron per cent.	95·73
2nd do. do.	95·87
Mean	95·80
Carbon, per cent., by loss	4·20

2. A larger quantity of the same mixture was heated in precisely the same manner. A number of small buttons and globules of metal were obtained. The buttons, when fractured, did not seem uniform in appearance; and some parts were easier to cut than others. The specific gravity of one button was 7·097. When hammered it split at once. In one part the carbon seemed to be in larger plates than the other. The iron was highly graphitic. Four determinations of the iron were made by standard solution of bichromate of potash:—

1st gave of iron per cent.	96·75
2nd do. do.	97·42
3rd do. do.	96·40
4th do. do.	96·03

Hence the metal was evidently not uniform in composition.

3. A mixture of sesquioxide of iron, made from sulphate and carbon, was heated in the same manner. A multitude of small globules, and one large one, were obtained. The crucibles were reheated with the view of melting all the globules into one, but this did not occur. The largest button was broken, and the fracture was quite unlike any of those in the preceding experiments. The specific gravity was 6·968. One piece, weighing 8·55 grains, was digested in hydrochloric acid, etc., the graphite collected as usual. Its weight was not changed by redigestion in strong hydrochloric acid. The iron was determined by standard solution of bichromate of potash:—

Iron.	per cent	95·66
Graphite	do.	4·56
		100·22

I examined some of the metal formed in the preceding experiments, in order to ascertain whether I could obtain clear proof of the presence in it of any combined carbon. It was dissolved in hydrochloric acid, when fetid hydrogen was disengaged. The washed residue was boiled with a solution of potass, but the latter did not become in the slightest degree coloured, nor on neutralization with hydrochloric acid did any precipitate occur; but when cast-iron containing any sensible amount of combined carbon is treated in this way, the potash solution is rendered brown, and, when neutralized by acids, deposits brown flocks of carbonaceous matter. It appears certain, then, that if not the whole, very nearly the whole, of the carbon in the iron reduced in the preceding experiments was in the state of graphite.

4. The subjoined experiments have been made in my laboratory by Mr. Hochstätter. Anhydrous sesquioxide of iron artificially prepared, free from sulphur, but not entirely from silica, was employed. Of this oxide 250 grains were intimately mixed by trituration with a considerable excess of charcoal. The mixture was subjected in a brasqued crucible during 8 hours (not consecutively, but in the course of 2 days, 4 hours each day) to a *comparatively low temperature*. A well-melted button was obtained, weighing 179 grains, grey, dull, and granular in fracture, but not largely so. It contained 95·85 % of iron. No determination of the carbon was made. There was no distinct appearance of graphite on the fracture, nor was any found on the top of the button. The hydrogen evolved from it by the action of hydrochloric acid had a slight odour of sulphuretted hydrogen.

5. Of the same sesquioxide of iron, as used in the last experiment, 500 grains were intimately mixed with 100 grains of Ceylon graphite (which contains about 1½ % or 2 % of earthy impurity). The mixture was put into a plumbago crucible, and the space above was filled with plumbago well pressed down. The crucible was covered, and exposed during 8 hours to a *comparatively low temperature*, as in the last experiment. It was rapidly cooled, and at the bottom was a well-melted button weighing 347·5 grains. On the top of this button were brilliant scales of graphite, which seemed to have been separated from the iron. The fracture of the button was dark-grey, presenting small bright

scales of a highly graphitic lustre. The metal contained 95·13 % of iron, and 4·63 % of graphite, which was directly determined with every precaution.

Schafhäutl informs us that he has "observed that graphite is never generated in melting-pots from pure iron and pure carbon, except when the black oxide of the surface began to attack the sides of the crucible."[7] Graphite was certainly generated in the preceding experiments, in which contact between oxide of iron and the sides of the crucible was effectually prevented by a carbonaceous brasque free from silicon. In the paper from which the above extract is taken, Schafhäutl discusses the conditions essential to the formation of graphite; but I venture to assert that whatever his observations and experiments may be, his reasoning is unsatisfactory. Conclusions are drawn from premisses which are mere assumptions. There is an air of affected minuteness and elaboration about the papers which this author has published on iron and steel which is hardly calculated to produce conviction in the mind of any chemist skilled in manipulation, and accustomed to sound chemical arguments. There can be no objection to the emission of hypotheses by the score, so long as it is clearly understood that they are put forth only as hypotheses; but in the present day they should not be obtruded upon us as though they were rigid inductions from trustworthy data. This is a grave error, and it is one with which Schafhäutl may be justly charged.

The following experiments were made by Sefström:[8]—Wire made of Taberg iron was put into a carbon crucible, covered with carbonate of lime, and heated in a blast-furnace during 1½ hour. A well-melted button of cast-iron was obtained, of which the fracture was grey and foliated. The iron increased 4·34 % in weight. Åkerby steel, heated under these conditions, was also converted into the same kind of cast-iron, with an increase of 3·89 % in weight. Another experiment was made of heating iron wire placed upon lime, and covered with charcoal. It melted completely, and increased 3 % in weight. The fracture of the button had an unusual aspect: towards the surface it presented a thin velvet-black border, but within it was silver-bright, and had flat crystalline facets so large that they almost extended across the button. It was as hard as slightly-hardened steel, and had considerable malleability. On repeating this experiment a button was produced which was dark on the surface and white within, compact but never crystallized. No difference in the result was observed when caustic lime was used instead of carbonate.

Iron, manganese, and carbon. By Mr. Dick —Brown oxide of manganese (Mn^3O^4) was prepared by calcining pure carbonate of protoxide of manganese. A mixture of 400 grs. of sesquioxide of iron, 12 grs. of brown oxide of manganese, and 92 grs. of carbon, was heated intensely in a clay crucible brasqued with pure carbon. Several buttons were obtained; the largest was fractured and analysed; its specific gravity was 7·60;

[7] Phil. Mag. 15, p. 423. 1839.
[8] Journ. f. techn. u. öconom. Chem. Erdmann, 10, p. 163. 1831.

it contained graphite, which after the usual treatment was weighed; its weight was unchanged by subsequently boiling in a strong solution of caustic potash. The iron was separated as basic acetate. The results of the analyses are as under:—

Iron	95·97	96·26
Manganese	3·21	3·14
Graphite	0·56	0·40
	99 74	99·80

This result has much surprised me, as I expected to find a considerable amount of combined carbon in the product, owing to the presence of manganese; but I would not venture to draw any conclusion from a single experiment of this kind. The degree of temperature at which reduction takes place, there is reason to believe, may greatly modify the result.

Modes of existence of carbon in iron.—It is generally admitted that carbon may exist in solid iron in a state of combination and in a state of mechanical diffusion through the mass as graphite. It is usual to apply the terms, combined and uncombined, to these two modes of existence respectively. Graphitic carbon is supposed to separate during the solidification of iron after fusion, just as silicon is supposed to separate in the graphite-like state from zinc under similar conditions. When graphitic iron is melted *per se*, the graphitic carbon, does not remain isolated, and by virtue of its having a lower specific gravity than iron, rise and collect at the top of the liquid metal, but disappears and redissolves in it. When iron contains much graphitic carbon its fracture is dark grey, granular or scaly-crystalline; it is then called *grey-iron*. When, on the contrary, iron contains much combined carbon, its fracture is more or less white, granular or crystalline, and sometimes very largely so; it is then called *white-iron*. Grey-iron passes by insensible gradations into white-iron; and at certain intermediate stages the grey and white kinds are visible on the fractured surface of the same iron, constituting what is called *mottled iron*. The French designate such iron by the appropriate name of *fonte truitée*, or trout-iron, from its being speckled with spots like that fish. From the extreme of greyness to absolute whiteness not less than eight varieties are frequently recognized, and these are distinguished by the numerals from 1 to 8 respectively. Thus No. 1 is the greyest iron, No. 2 less grey, and so on till No. 5, when mottled iron begins, the prevalence of white-iron over the grey increasing successively to No. 8, which is white-iron. An experienced eye will determine at a glance the particular number by the appearance of the fracture. These observations, it must be borne in mind, only apply to iron containing much carbon, i. e. *cast-iron*.

There may be no visible proof of the existence of combined carbon in iron, or, in other words, no appearance of white-iron; and yet combined carbon may be present in a very sensible proportion. Conversely, white-iron may contain a sensible proportion of graphitic carbon, although it escape detection by the eye. It is at least doubtful whether

even the greyest iron does not contain some combined carbon, but white-iron may be so white as to be entirely free from graphitic carbon.

The mode of existence of carbon in iron is in great measure determined by the conditions of solidification after complete fusion, and the temperature at which fusion has been effected. Rapid solidification favours the retention of carbon in the combined state, and by this means it is possible to convert characteristic grey-iron into perfectly white iron. Thus by pouring liquid grey cast-iron into a cold metallic mould, so as to cause the most sudden cooling possible, the exterior of the solid iron, where it comes in direct contact with the mould, will be found to be in the state of white-iron, while the interior will be in the state of grey-iron. This principle is extensively employed in practice, in the process known as *chill-casting*. It is adopted when it is desirable to render the surface extremely hard, white-iron being intensely hard as compared with grey-iron. Not all grey-iron can be converted into white by this means, as the result of the following experiment will demonstrate:—

Through the kindness of my friend Mr. S. H. Blackwell, a portion of the cast-iron from one of his blast-furnaces near Dudley was allowed to run over a cold cast-iron plate, and another portion at the same time to run over a similar plate, after which cold water was immediately dashed over the latter; a third portion from the same tapping was also allowed to run into a hollow termed the "roughing-hole," and there left to cool very slowly under a large mass of hot slag. The first two specimens were ⅛ in. thick, finely granular on fracture, decidedly grey, and presented no indication of white-iron. The other portion cooled very slowly, was grey, and largely crystalline.

But the mode of existence in carbon is in a certain degree determined by the conditions under which the solid metal is heated and cooled at temperatures very far below its melting-point. Thus it has been found that steel, in the hardened state, yields no sensible residue of graphite by the solvent action of acids, and that, on the contrary, the same steel in the softened state yields by such action a sensible amount of graphitic residue. Professor Abel, of the Arsenal, experimented on this point a few years ago, and found that hardened steel-wire dissolved in hydrochloric acid without residue, whereas the same steel softened yielded a dark, flocculent, carbonaceous residue when acted upon by the same acid. The most recent experiments on this subject are those of Caron.[9] He found that steel in the three states of blister-steel, tilted steel, and hardened steel, for 100 parts of metal dissolved yielded, respectively, the following proportions per cent. of insoluble residue: 1·624 (A), 1·243 (B), and 0·240 (C). These residues were analysed, and the results are as under:—

	A.	B.	C.
Carbon	0·825	0·560	traces
Iron	0·557	0·445	traces
Silica	0·242	0·238	0·240
	1·624	1·243	0·240

[9] Comptes Rend. 56, p. 43, Jan. 1863.

It is remarkable that the operation of hammering, *per se*, should induce any change in the mode of existence of the carbon in steel. But Caron found that rolled steels, *cæteris paribus*, yielded a larger amount of carbonaceous residue than hammered steels. This, Caron remarks, agrees with the observation that the action of rolls is less powerful than that of the hammer in improving the quality of steel. By a similar series of experiments and analyses Caron ascertained that the effects of heat were sensibly the reverse of those produced by hammering and hardening. Thus hardened steel, having been annealed during periods from a few hours to several days, has, on solution, yielded amounts of free carbon proportionate to the duration and intensity of the process of annealing; and to the steels thus softened their original qualities or chemical properties with respect to acids are only restored by hammering or hardening. However long the process of annealing, a little carbon always remains in the combined state. Caron found this to be the case after annealing during 15 days and 15 nights.

We have now to inquire as to the proof of the existence of carbon in a state of *chemical* combination in iron.

Spiegeleisen or specular cast-iron is always, as its name implies, largely crystalline, its fractured surface presenting bright mirror-like cleavage-planes. It is not unfrequently met with in large intersecting tabular as also in massive crystals, but the system to which they belong does not appear to have been clearly ascertained. The prevalent opinion, however, seems to be that they are not cubical. Numerous analyses of spiegeleisen have been published, in which the carbon is given as about 5 %, and in which it is represented as existing wholly or in great measure in the combined state. This corresponds to the formula Fe^4C, which by calculation gives 94·92 % of iron, and 5·08 % of carbon. Hence this variety of cast-iron is regarded as a definite chemical compound. It may, however, be urged against this conclusion that in all the published analyses of specular cast-iron manganese appears as a constituent, seldom less than about 4 %, and often much more. Now, notwithstanding the close chemical relation between iron and manganese, we should not be justified in accepting the formula Fe^4C as established, unless it can be shown that the presence of manganese is not essential. The question then arises whether any trustworthy analyses of specular cast-iron having this formula, but without manganese, can be adduced. I have sought in vain for such analyses, and every specimen of *characteristic* specular cast-iron which I have examined has contained a very sensible proportion of manganese. In metallurgical books statements of an opposite kind appear. Thus, in the tabular list of analyses of specular cast-iron in Kerl's Handbook,[1] there are three by Karsten, in which the chemically-combined carbon ranges from 4·121 % to 5·112 %, and in these there is no allusion to the presence even of a trace of manganese; yet in Karsten's own record of these analyses it is expressly stated that manganese was

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[1] 1, p. 253. 1855.

not sought for.[2] Kerl cites an analysis by Schafhäutl of a so-called spiegeleisen from Alais, in which the carbon is given as wholly in the combined state, and as 5·80 %, without a trace of manganese; but this specimen, we are informed, contained 0·65 % of sulphur, 1·86 % of silicon, 0·11 % of aluminium, 4·05 % of arsenic, and 0·87 % of nickel; and consequently it furnishes no argument in support of the formula Fe^4C. The spiegeleisen which Schafhäutl in his article on Steel presents as a typical example of this variety of cast-iron, was found by him to have the following composition:[3]—

Iron	88·961
Carbon	5·440
Manganese	4·003
Silicon	0·179
Nitrogen	1·200
Copper	0·166
Tin	0·116
	100·065

Gurlt, in a paper on the compounds of carbon and iron, states that spiegeleisen of the formula Fe^4C "is rarely met with in a state of absolute purity."[4] He does not inform us that he has ever seen it absolutely pure, and it may therefore be presumed that he has not.

Bromeis, many years ago, came to the conclusion that other substances besides carbon might communicate to iron the property of crystallizing like spiegeleisen; and he writes, "If in all these analyses we seek for such a substitute [for carbon], we find it only in the extraordinarily high content of manganese, which in the spiegeleisen examined by me amounted even to 7 %."[5] A fine quality of German spiegeleisen analysed in my laboratory by Mr. Tookey contained 11·12 % of manganese and 4·77 % of carbon. The late Mr. T. H. Henry found 11·50 % of manganese in spiegeleisen made from Franklinite in the United States, and not less than 6·90 % of carbon. Richter of Leoben in Styria found 7·578 % of manganese and 1·902 % of silicon in a spiegeleisen from Jauerburg in Carinthia. In another specimen from Theresienthal in Bohemia the same observer found 22·183 % of manganese, 2·732 % of silicon, and not more than 2·311 % of carbon. It was not attractable by the magnet, and it did not throw down metallic copper from a neutral solution of the chloride (CuCl), but reduced it merely to dichloride (Cu^2Cl), which separated.[6]

The data which have now been advanced negative the existence of a solid compound of the formula Fe^4C, but appear to establish that of a solid compound of the formula $(Fe,Mn)^4C$, or of one of which the composition may be nearly represented by that formula, the ratio between the equivalents of iron and manganese being in round numbers about 20 : 1. The adjective solid is used designedly, for it is con-

[2] Eisenhüttenkunde, 1, p. 592. 1841.
[3] Chemical Gazette, 14, p. 230. 1856.
[4] Technologische Encyklopädie. Prechtl. 15, p. 364. Stuttgart, 1847.
[5] Annal. d. Chemie u. Pharm. 43, p. 246.
[6] Berg-u. Hüttenmännisches Jahrbuch G. Faller. 11, p. 295. Wien, 1862 (Continuation of Tunner's Jahrbuch).

ceivable that a compound having nearly at least the formula Fe^4C may yet exist in the liquid state. In the regulus called *blue metal* of the coppersmelter we have seen that, in the act of solidification after fusion, metallic copper separates, which there is good reason to believe was in a state of chemical combination while the regulus was liquid. When iodine is dropped on iron-filings which have been rapidly heated to redness in a porcelain crucible, combination takes place; and the product, after having been heated to bright redness, evolves iodine on cooling below redness. A periodide of iron seems therefore to be formed, and to exist only at the higher temperature; for after cooling a grey lamellar mass remains, which is pure protoiodide of iron.[7] We have also seen that when pure iron is exposed to a high temperature, in contact with an excess of pure charcoal, a comparatively fusible metallic substance is produced, which certainly contains, either in a state of chemical combination or in a state of solution, between 4 % and 5 % of carbon; and that this carbon may separate during solidification in what is termed the uncombined or graphite state. Now when we consider the absolute infusibility of carbon at the highest temperature which we have as yet been able to attain, and when we further consider the extremely high melting-point of pure iron, it seems reasonable to conclude that when these elements unite to form cast-iron, which is so easily fusible as compared with pure iron, they enter into chemical combination with each other. If indeed it be not so, then, so far as I am aware, the fact is an anomaly without a parallel in chemistry; but admitting that it is so, it does not necessarily follow that a compound of iron and carbon may not have the property of simply dissolving additional carbon, and in that case the amount of carbon might be expected to increase with the temperature. This would explain the copious production of graphite, sometimes in large flakes, which not unfrequently occurs in the smelting of iron in the modern blast-furnace. The temperature is much higher at some distance above the hearth, where the liquid cast-iron accumulates, than in the hearth itself. One of the conditions which, it is well known, are essential to the formation of very grey, or, in other words, of very graphitic iron, is great elevation of temperature. The other conditions are extensive and comparatively prolonged contact of the reduced iron with carbonaceous matter; and the first of these conditions necessarily involves, in a greater or less degree, the other.

Notwithstanding the attention which has been directed to the study of the combination of iron with carbon, there are to my mind many points which are still very obscure, especially with respect to graphitic iron. It occurs to me as possible that carbon may, as suggested by Berzelius in explanation of the differences between certain isomeric compounds of carbon and hydrogen, etc., exist in iron in the two allotropic states of graphitic and amorphous carbon, or, as he distinguishes them, $C\beta$ and $C\gamma$;[8] and that a very high temperature developes the

[7] Wanklyn and L. Cariu.. Ann. de Chim. et de Phys. 3. s. 64, p. 484. 1862.
[8] Tr. 1, p. 264.

first of these. I do not however find that in remelting characteristic spiegeleisen under plate-glass, at a temperature sufficient to melt wrought-iron with facility, there is any separation of graphite, or any sensible change in the external characters of the metal. Gurlt states "it is known from experience that white pig-iron may be converted into grey, causing a separation of carbon in the form of graphite, by exposing it to a degree of heat much above that required to effect its fusion; specular [cast] iron may even be converted into grey cast-iron in this way."* I am certain that in my experiment above-mentioned the spiegeleisen was heated far beyond its melting-point, yet without becoming grey iron.

If we admit that carbon may exist in molten iron in the two allotropic states of amorphous and graphitic carbon, the question naturally arises whether the graphitic can again become amorphous carbon. We know that the latter may pass into the former by the action of intense heat. This question might probably be solved by exposing mixtures of pure iron and pure graphite to varying temperatures.

Berthier conceived that he had discovered a definite carbide of iron of the formula FeC, and the evidence on the subject is as follows:[1]— "Cast-steel, broken in pieces from 2 to 3 centimetres (0·79 in. to 1·18 in.) long, having been put to digest in water mixed with bromine or iodine in insufficient quantity to dissolve all the iron, and the liquor decanted, after the lapse of several days, at the moment when the bromine and iodine were nearly saturated, the pieces of steel which were found at the bottom of the vessel had preserved their form and original appearance, and it seemed that they had undergone no alteration; but, on the contrary, it was soon ascertained that they had been strongly attacked. They retained indeed some degree of consistency, but broke between the fingers like pieces of charcoal; they were compact, fine, and close-grained in fracture like steel, and had a feebly metallic black-grey colour; they marked paper grey like plumbago, and might have been used as pencils; on scratching these pieces with a penknife there remained a solid part in the shape of a needle, which formed their axis and was steel intact. The portion attacked being again treated with bromine or iodine, was converted into pure carbon, iron being dissolved: hence it was carbide of iron. Analysis showed that this carbide was composed exactly of one atom of each of its elements, or of 81·7 % of iron and 18·3 % of carbon. It was magnetic, and perfectly attackable by bromine, iodine, and hydrochloric acid, but only when isolated. In contact with iron, this metal first dissolves. When pieces of steel are treated with bromine or iodine they are gradually transformed from the surface to the interior, by way of cementation, into the carbide FeC; and so long as any unchanged steel remains in the centre, the carbide enveloping this steel is homogeneous, and does not contain less than one atom of iron for one atom of steel, even at the surface; but as soon as the last traces of steel are destroyed, the carbide itself yields to the action of the bromine or iodine; and if the solvent

* Chemical Gazette, 14, p. 234. 1856.

[1] Ann. d. Mines, 3. s. 3. p. 229.

is employed in sufficient proportion, it gives up the whole of its iron, and is transformed into pure carbon."

It does not appear that Berthier's conclusion has ever been confirmed, and no single observation of the kind should be received as satisfactory. The fact that the insoluble residue was composed according to the formula FeC may have been a mere coincidence. It is not stated that this residue had identically the same composition in every part of the mass; and even if this had been shown to be the case, it would not necessarily follow that the alleged monocarbide pre-existed in the steel. Caron has in vain endeavoured to procure the definite carbide of Berthier by the solvent action of bromine or iodine upon steel. In every instance this pretended carbide of iron varied in composition, not only with the quality of the steels and the nature of the solvents employed, but also with the form and size of the specimens operated upon. Hence Caron concluded that the carbide of Berthier was probably only a mixture of carbon and metal, in which the latter was mechanically protected by the carbon from solvent action.[2]

Berzelius admitted the existence of carbides of iron having the formulæ FeC^2 and Fe^2C^3.[3] The method which he recommended as the best for obtaining the first of these compounds in a state of purity is the distillation of ferrocyanide of ammonium in a retort. At first cyanide of ammonium and water pass over together, and then nitrogen is evolved. If, towards the end of the operation, the carbide of iron remaining is heated to redness, it takes fire, and seems to burn for an instant as though in oxygen gas; but this phenomenon quickly disappears. Should part of the cyanide of iron have escaped decomposition, it is decomposed during this rapid rise of temperature, and nitrogen is disengaged with violence. According to Berzelius this phenomenon of light has the greatest analogy to that observed in heating hydrated sesquioxide of iron, and "is due to the fact that the carbide of iron passes from one isomeric modification to another." The carbide of iron thus obtained is described as an incoherent black powder which takes fire when gently heated, and burns like tinder, yielding a residue of sesquioxide of iron equal in weight to itself. The carbide of iron of the formula Fe^2C^3 is prepared by heating pure Prussian blue in the same manner; water, a little cyanide of ammonium, and much carbonate of ammonia, pass over, and there remains in the retort the carbide, which produces the same phenomenon of light as that above described. Liebig and Gerhardt[4] have accepted these residues as combinations of carbon and iron, but others believe them to be only

[2] Comptes Rend. 56, p. 44, Jan. 1863.

[3] Tr. 2, p. 692. 1846. Vid. also the edition of 1831, 3, p. 270. There is an important error in the most recent edition, which does not occur in the first. In reference to the incandescent phenomenon it is stated "comme du gaz oxygène" instead of "comme dans du gaz oxygène." The passage in Gmelin's Handb., by the Cavendish Society, in which the process of making carbide of iron is described, is to me quite unintelligible (7, p. 432): "When [ferrocyanide of ammonium is] more strongly heated in contact with air, it turns brown, and is then converted into black bicarbide of iron, which, at a still higher temperature, exhibits a glimmering light, and if heated in the air, burns like tinder," &c.

[4] Traité de Chim. Organ. 1, p. 157. 1840. Traité de Chim. Organ. 1, p. 326. 1853.

mixtures of carbon and iron slightly carburized. Robiquet is of this opinion, and urges in support of it the not very conclusive facts that the residues are very magnetic, are easily rusted in moist air, and that acids very readily extract the iron from them.[5] The phenomenon of light well deserves attention, and possibly nitrogen may play an important part in it, as titanium has been shown by Wöhler to burn in that gas with considerable incandescence. These alleged carbides of iron require and merit further investigation, and nitrogen especially should be looked for in them.

Formerly it was concluded from Karsten's experiments on the action of acids on certain varieties of iron containing carbon, that there existed in the insoluble residue a definite carbide of the formula FeC^3; and this compound has often been described in chemical as well as metallurgical treatises.[6] In Karsten's paper, previously adverted to, which was published in 1846, or five years after the second and last edition of his work on the Metallurgy of Iron, the author, as we have seen, admitted that there was no satisfactory proof of the existence of such a carbide. Bromeis informs us that he never succeeded in obtaining a definite compound of carbon and iron by the solvent action of acids; and therefore as no additional evidence has, so far as I am aware, been advanced on the subject, the carbide in question can no longer be received. But even if its existence had been demonstrated, it would not, as I have remarked in reference to Berthier's alleged monocarbide of iron, necessarily follow that it pre-existed in the iron.

Gurlt admits the existence of pure tetracarbide of iron (Fe^4C) as demonstrated, and maintains that there is also an octocarbide, Fe^8C, which he was the first to recognize.[7] It is distinguished, he informs us, from the tetracarbide not only by its chemical composition, but also very distinctly by its crystalline form and other physical properties. It belongs to the regular or cubical system, and almost always occurs "in confused octahedral groups, with the planes not well defined, but the angles occasionally sharp." He analysed a piece of such crystallized cast-iron from Gleiwitz in Upper Silesia, from the core of a cast-iron gun, and found it to have the following composition:—

Carbon, combined	2·46
Ditto graphitic	2·84
Silicon	0·26
Iron	94·20
Sulphur and phosphorus	traces
	99·76

He considers a small portion of the combined carbon as replaced by silicon, and expresses what he conceives to be the rational constitution of this metal by the following formulæ:—

Fe^8C	94·008
Fe^8Si	2·920
Graphite	2·840
	99·768

[5] Berthier, T. 2, p. 209.
[6] Vid. Gmelin's Handb. 5, p. 203.
[7] Chemical Gazette, 14, pp. 230 et seq. 1856.

"In the former constituents," he writes, "the carbon is to the iron as 1 : 37·3, and in the latter the silicon is in the proportion of 1 : 10·0, closely agreeing with the calculated composition; and as the octocarburet so largely preponderates in this compound, one is fully justified in describing it as such." He assigns to this supposed octocarbide the following characters:—Specific gravity, 7·15; colour, iron-grey; much less hard and brittle than the tetracarbide, retaining the impression of the hammer when struck; and less fusible than the tetracarbide. It is frequently met with in cavities in large castings of grey iron, such as rolls and pieces of ordnance. The crystals usually occur in pyramids as much as 2 lines broad, and are often beautifully iridescent; but these crystals, Gurlt adds, are not to be confounded with those of soft malleable iron, which are sometimes produced during the processes of refining and puddling, as these "contain no carbon, and are so free from foreign matters that they may be considered as nearly chemically pure iron."

Such is the evidence which, according to Gurlt, suffices to establish the existence of octocarbide of iron. Now we know that iron crystallizes in the cubical system, and we know further that a body may contain a large amount of foreign matter and yet crystallize, sometimes with great distinctness, in its own system. Where, then, we may ask, is the proof that these alleged crystals of octocarbide of iron were anything more than crystals of iron impregnated with graphite and a carbide of iron certainly not an octocarbide? None has been adduced, and until we have such proof we may fairly decline to accept the octocarbide, though we do not pretend that the existence of such a compound is impossible or even improbable. Carnall met with octahedrons in a blister in the rim of a wheel made from fine-grained mottled cast-iron. He believed them to have the same composition as the surrounding metal;[8] and Hausmann states that in common white iron (not spiegeleisen), which had been long exposed to a high temperature, he found crystals exactly similar to those occurring in grey cast-iron. After this exposure the metal had precisely the same coarsely laminar fracture, with "three-sided rectangular laminæ" through the mass, as wrought iron acquires under these conditions.[9]

Concisely stated, Gurlt's views appear to be as follow:—Grey iron is an octocarbide intermingled with graphite; specular cast-iron, *i. e.* iron combined with the maximum of carbon, is a tetracarbide; and mottled iron is a mixture of the two. He conceives that the tetracarbide, which is stated to be formed at a comparatively low temperature, is resolved at a higher temperature into octocarbide and graphite; and hence he suggests the probability that the octocarbide is always formed from the tetracarbide. With respect to these views it may be remarked that at present there is no satisfactory proof of the existence of such a solid pure octocarbide of iron as Gurlt assumes, and that the statement as to the conversion of spiegeleisen containing manganese

[8] L. u. K.'s Jahresb., Continuation of, 1859, p. 202.

[9] Jahresbericht, Continuation of Liebig and Kopp's, 1858, p. 189.

into grey iron, by simple exposure to a temperature considerably higher than the melting-point of the former, requires confirmation. It may be that I failed to obtain this conversion from not having kept the spiegeleisen exposed to a high temperature for a sufficient time; for Gurlt indicates that the decomposition of the tetracarbide may be incomplete, "owing to the necessary temperature not being sufficiently protracted." Whether this be so, I know not; but I consider it improbable. If Gurlt's views were established, it would seem to follow that carbon may exist even in *liquid* cast-iron, in the two allotropic states of amorphous and graphitic carbon; for otherwise why should graphite separate, during solidification, from spiegeleisen, which has merely been exposed to a higher degree of heat than its melting-point, and none separate from the same kind of cast-iron during solidification after fusion at or somewhat beyond its melting-point? Gurlt's theory has certainly the merit of simplicity, difference of temperature explaining everything; but simplicity, to have any value, must be founded in truth, and this cannot be alleged with certainty of the theory in question. This theory, however, has not the merit of much originality, as in its most essential points it closely resembles that long before propounded by Karsten.

Gurlt illustrates his paper on the compounds of carbon and iron with a selected series of analyses of various kinds of cast-iron, and has endeavoured to express their rational constitution. The first on the list is one by Karsten, of spiegeleisen made from spathose ore. It is given exactly as follows:[1]—

Carbon	5·112	Fe^4C	Fe	94·188	99·300
Sulphur	0·001		C	5·112	
Iron	94·887	Fe^6S	Fe	0·014	0·015
Copper.........	trace		S	0·001	
	100·000			99·315	

How far this is correctly cited the reader shall judge for himself, from the following literal transcript from Karsten's table of analyses of various kinds of pig-iron.[2]

From whence.	Carbon. Uncombined.	Carbon. Combined.	Carbon. Total.	Sulphur.	Phosphorus.	Silicon.	Manganese.	Copper.
*9. From Saynerhütte	† †	5·1117	5·1117	0·001	†	†	†	†

The sign (†) indicates that the substance was not sought for, and the sign (††) that it was sought for, but not found. This is the analysis which is presented by Gurlt as I have given it above. It will be immediately observed that the 94·887 % of iron is a mere assumption by Gurlt, and that *manganese* even was not sought for by Karsten. Further comment is unnecessary. Gurlt adduces analyses by himself of Scotch iron in support of his views. He employed chloride of silver

[1] Chemical Gazette, 14, p. 255. [2] Eisenhüttenkunde, 1, p. 592.

as a re-agent, and obtained an insoluble residue which he believed to consist of silver, graphite, carbon, and silica.[3] The weight of this being determined, he boiled a portion of it with caustic soda, which dissolved "the silica and chemically-combined carbon," etc., and the latter was estimated by difference. Now, the solution of pure carbon in any state would be a new fact in chemistry; but it will be shown that what was thus regarded as pure carbon by Gurlt was not pure carbon, so that so far his analyses must be erroneous.

The reader cannot fail to perceive how unsatisfactory our information still is concerning the modes of the existence of carbon in iron and their causes. The conclusions at which Karsten and others have arrived on this highly interesting and not less important subject appear to me to be vitiated in a greater or less degree by the fact, that the data upon which they are founded have been derived from observations and experiments upon the varieties of carburized iron of commerce, which never consist of iron and carbon alone, but always contain sensible proportions of other elements, especially sulphur, phosphorus, and silicon. That the presence of these elements, either separately or together, is not uninfluential will presently be demonstrated. It is only by operating upon pure iron and pure carbon that we can hope to obtain results entirely free from error; but those only who have attempted to experiment in this direction can fully appreciate the difficulties which have to be encountered, but which, happily, there is no reason to suppose are insurmountable. I would especially direct the attention of students and others, who may be desirous of selecting some promising metallurgical problems for original investigation, to the combinations of carbon and iron.

According to Karsten temperature is everything; and that it plays a very prominent part in determining the mode of existence of carbon in iron no one can doubt. But, whether it be so exclusively the agent as Karsten maintains, may fairly be questioned. I will now present, as succinctly as I can, a summary of his deductions on the subject, with a brief commentary thereon; and I shall translate, as literally as possible, the language in which they are expressed by the author.[4]

When white cast-iron is allowed to cool with the utmost slowness after fusion, it is not even then converted into grey cast-iron unless it has been melted at a much higher temperature than was required to bring it into the liquid state. By this variation in temperature, and in proportion to the slowness with which solidification takes place, the product will be obtained in the state of white, mottled, or grey cast-iron. A porous variety of white cast-iron, which the Germans call "luckige Floss," and steel containing much carbon, may, like white cast-iron, be converted into grey cast-iron, by keeping them for some time melted in a clay crucible at an extremely high temperature, and afterwards letting them slowly solidify with the greatest care. If the temperature has not been high enough, only soft grey iron is produced, which contains no uncombined or graphitic carbon, but only a poly-

[3] Chemical Gazette, 14, p. 259.

[4] Eisenhüttenkunde, 1, p. 577 et seq. 1841.

carbide, *i.e.* the carbon is not combined with the whole of the iron, but exists as a carbide of unknown composition, designated polycarbide, intermixed with comparatively pure iron, or with iron rather in which only a little carbon is present. This polycarbide is formed, though to a less extent than under the above-mentioned conditions, by merely heating to redness and slowly cooling afterwards, more carbon in this case remaining in combination with the whole mass of the iron. This is the reason why hardened steel is so much softer, the longer and the more strongly it is heated. White cast-iron, with the characteristic fracture of specular cast-iron, by heating to redness and slowly cooling afterwards, with perfect exclusion of the air, does not change into grey and soft iron containing polycarbide, probably because it is a neutral product, and the iron and carbon are in the state of mutual combination and saturation. This iron, in order to be converted into *grey cast-iron*, must necessarily be exposed to a melting heat inversely proportionate to that required simply to render it liquid.

On the contrary, in order to render soft steel, or wrought-iron, annealed at a red heat, and which still contains a sensible quantity of carbon, hard and white by sudden change of temperature, the temperature—in so far as merely heating to redness is sufficient for the purpose—must be as much higher, and consequently the change of temperature by sudden cooling as much greater, as the amount of carbon in the iron is smaller. In grey cast-iron, the carbon present in the uncombined state takes no part in this change; and it will, therefore, depend on the quantity of combined carbon in this kind of iron, whether the hardness of the latter be considerably increased by sudden cooling after heating to redness. By the long continued exposure of graphitic grey cast-iron to a stronger heat, yet below its melting-point, it is actually more or less completely changed into grey soft iron, which by sudden cooling becomes considerably harder and whiter, and which by slow cooling remains soft, notwithstanding it contains very much polycarbide and little graphite; but this is a result of a peculiar kind, which cannot be attained by rapid heating to redness. In this case the graphite or the carburized iron acts the same part as the carbon in the conversion of bar-iron into steel by cementation; and, indeed, grey cast-iron may even be substituted for carbon in this process. If grey cast-iron is to be changed into white by sudden cooling, it must not be fused at a temperature considerably higher than its melting-point. The more graphite it contains, the more quickly follows the change by sudden solidification. Grey cast-iron, which only contains little graphite, yields to this change with great difficulty; and the reason is, that this kind of cast-iron requires for its fusion a very strong heat, which cannot be so quickly and completely extracted by sudden solidification.

This theory of Karsten is ingenious; but let it be borne in mind, that it rests on the assumption of the existence of a polycarbide of iron, which he never succeeded either in isolating or preparing, and the composition of which he regarded as doubtful. That iron and carbon do actually enter into chemical combination, no one I presume

will doubt; and if so, then, if the theory of definite proportions be true, there must at least be one definite compound, and there may be several, of these elements which is capable of dissolving in, or being dissolved by, iron. It is true that the melting-point of pure iron is very much higher than that of the metal when carburized in a sensible degree; yet there is no reason why metals should be considered as exceptional in the case of solution. Thus mercury, which is fluid at the ordinary temperature, immediately liquefies silver, gold, or copper; and the difference between the melting-points of mercury and these metals is proportionately far greater than between the melting-points of carburized iron and pure iron. Molten lead also readily dissolves silver, and many other similar examples might be mentioned. However, in all these cases, there is chemical action as well as solution. Definite compounds or alloys are first formed, and these dissolve in the excess of the mercury or molten lead. Perhaps it may be objected that in this case analogy does not hold good, because carburized iron is not a metal, but a metallic compound. When, however, I reflect upon the phenomena of solution generally, I am not disposed to attach much weight to this objection.

The chief facts and opinions which we have passed in review as to the modes of existence of carbon in iron may be conveniently condensed as follows:—

Carbon may exist in molten pure cast-iron in such a state that, during solidification, under ordinary conditions, it separates wholly or nearly so as graphite, which remains diffused through the solid metallic mass. The proof of this is afforded by chemical analysis, and will be particularly examined hereafter. By the action of acids the iron is dissolved, and graphitic carbon, sometimes in flakes of considerable size, is obtained as an insoluble residue. But it may be asked whether—admitting that carbon may actually combine with iron, and when thus combined retain its allotropic character—the fact of graphitic carbon being left by the solvent action of acids is certain evidence that this carbon was not present in the solidified metal, at least in a certain degree, in chemical combination with the iron. With regard to any distinct flakes of graphite which may be separated there can be no reasonable doubt, though, according to my experience, even they retain iron in some form or other which it is difficult to dissolve out completely. Not always, however, is the graphite obtained in distinct flakes. Moreover, when we carefully inspect the fractured surface of a piece even of highly graphitic iron, every part presents more or less of a characteristic graphitic lustre, yet not a trace of graphite can be detached with the point of a penknife.

In molten graphitic iron, the carbon must be either wholly in chemical combination or wholly in solution, or partly in chemical combination and partly in solution.

A high temperature appears to be necessary for the production of graphitic iron.

Slow solidification after fusion is the condition favourable to the separation of graphitic carbon in laminæ or flakes.

Accepting, for the sake of argument, the hypothesis of the existence of carbon in molten grey iron in the allotropic state of graphite, and admitting that such iron may by sudden cooling be converted into white iron,—which I am not aware has been ever demonstrated by experiment in the case of pure grey iron, *i.e.* consisting of pure iron and pure carbon—this white iron would constitute a specific variety.

Carbon may exist in such a state in molten cast-iron or steel, that during solidification, if rapidly effected, no graphitic carbon can be detected by the solvent action of acids in the solid metal, which then possesses the characteristic properties of what is termed white iron. This kind of iron, it is generally maintained, is only produced at a temperature which is described as low, compared with that at which grey or graphitic iron is formed. But, if I mistake not, hitherto all observations and experiments in reference to this variety of cast-iron are so far inconclusive, that they have not been made upon metal consisting of pure iron and pure carbon. However, assuming that they are conclusive, as may hereafter be proved to be the case, it would appear that the whole of the carbon may be present in the solid metal in the state either of mechanical diffusion or of chemical combination, or, according to Karsten, in chemical combination only with part of the iron, constituting a definite carbide of unknown formula (polycarbide), the rest of the iron retaining only a very small amount of carbon or none at all.

Slow solidification after fusion at a comparatively low temperature, according to the same observer, is the condition favourable to the formation and separation of this supposed polycarbide, just as the same condition of solidification after fusion at a very high temperature is favourable to the separation of graphitic carbon from grey iron. By exposure to a red heat, *i.e.* far below the melting-point of any kind of cast-iron, the supposed polycarbide, which may be present in solid iron, may be destroyed; or, in other words, the iron in the free state may combine with the polycarbide and so form one homogeneous metallic mass, provided the metal be afterwards suddenly cooled. Conversely, by again heating this mass to redness and slowly cooling afterwards, the polycarbide may be reproduced.

The carbon in this variety of cast-iron, it is conjectured, may be in the allotropic state of amorphous carbon, and may be susceptible of conversion into graphitic carbon by exposure to a very high temperature. It is with design that I here employ the word *conjectured;* for no other ought to be used in the present state of our knowledge.

Supposing that carbon may exist in molten grey iron in the allotropic state of graphite, it is not yet known whether under any conditions it may revert to the state of amorphous carbon.

The following observations of Karsten bear upon the subject under consideration, and well merit the attention of practical men.[5] When

[5] Eisenhüttenkunde, 1, p. 581.

grey cast-iron is heated far above its melting-point and poured into a mould, made of a bad conductor of heat, the fractured surface of the cold ingot presents no great difference in appearance in any part. Nevertheless, he ascertained from numerous experiments that the metal in the middle of the ingot always contained less carbon but more graphite than that towards the exterior. This he inferred was due to a difference in the composition of the supposed polycarbide in different portions of the ingot. The metal from the exterior contained besides graphite the polycarbide peculiar to white cast-iron and hardened steel; whilst the polycarbide from the central portion was far richer in carbon, and agreed with that in annealed white cast-iron and in softened steel. That the cast-iron in a liquid state, he remarks, was a uniform chemical combination can with difficulty be denied. He explains the difference of composition in the solid ingot by the longer continued exposure of the central portion to a high temperature during solidification than the outer portion. He thus accounts for the difference in the results in the determination of the carbon when different parts of the same piece of cast-iron are analysed even with the greatest care; and suggests that, consequently, the tenacity of the metal may vary in different parts of the same casting. Even in *chill-castings*, the white iron at the surface will contain more carbon than the inner kernel; but, when solidification is slowly effected, the outermost layer often contains as much as 1·75 % more carbon than the central part. In exemplification of this fact, the following experiment by Karsten may be adduced.[6]

Grey cast-iron, which before re-melting had a specific gravity of 7·1839, and contained 4·0281 % of carbon, of which 3·2469 existed as graphite and 0·7812 in the combined state, was melted in a reverberatory furnace and run into a thick cast-iron mould. The surface of the cold-casting to the depth of an inch was white and as hard as steel, and of this a portion was taken as well as another portion from the soft grey cast-iron in the middle of the ingot. The outer white iron had a specific gravity of 7·5467, and contained 5·0929 % of carbon wholly in the combined state. The inner grey iron had a specific gravity of 7·1753, and contained 3·8047 % of carbon, of which 3·1941 consisted of uncombined, and 0·6106 of combined, carbon.

On the action of silicon on iron containing carbon.—This is a subject of considerable practical interest. From the close chemical relations between these two elements, it is reasonable to anticipate that they might, at least in a certain degree, replace each other. The condition under which silica is reduced by iron in the presence of carbon is high temperature, or precisely that which is essential to the formation of graphitic iron. Accordingly, it is in this variety of cast-iron that the largest amount of silicon is generally found. But there are cases, as we have seen, in which silicon occurs in cast iron in unusually large quantity, exceeding even 6 %; but such cases are quite exceptional. Cast-iron containing 4 % or even 6 % of silicon

[6] Eisenhüttenkunde, 1, p. 583.

still resembles grey iron on fracture. It has long been observed, and in the first instance by Sefström, that the carbon in grey iron, in which much silicon exists, say from 2 % to 3 %. is wholly, or nearly so, in the graphitic state. Numerous analyses will hereafter be introduced which establish this point beyond question. It is not, however, to be hence inferred that the silicon has displaced the carbon; for we have seen that during the solidification of characteristic grey iron the carbon may separate completely, or nearly so, as graphite.

One of the first questions which obviously suggests itself in connection with this subject, is, whether silicon may separate, like graphite, during the solidification of grey iron containing it. The late Mr. Henry informed me that he had obtained certain proof that it does; and my own observations since have led me to the same conclusion.

Action of sulphur on iron containing carbon.—According to Karsten, sulphur expels carbon from iron at a high temperature. When iron containing the maximum of carbon, for example, spiegeleisen, is melted with sulphur in a covered clay crucible, carbon separates and collects on the under surface of the resulting sulphide of iron; it is soot-like, has no lustre, burns in a muffle with difficulty yet without residue, and was regarded by Karsten as a dull variety of graphite. When molten cast-iron, not containing the maximum of carbon, is poured upon sulphur of which the quantity is not sufficient to sulphurize all the iron, under the layer of sulphide of iron will be found the residual cast-iron richer in carbon than originally. Thus grey iron, containing 3·312 % of uncombined, and 0·625 % of combined carbon, and 0·029 % of sulphur, yielded, by partial conversion into sulphide, white iron with mirror-like cleavage planes which contained 5·488 % of chemically combined carbon, and 0·446 % of sulphur; it was covered with a layer of sulphide of iron.[7] By the addition of sulphur to molten cast-iron the carbon in the unsulphurized iron increases until it reaches the maximum; and on the further addition of sulphur, pulverulent carbon separates, as above described. There is one point about this experiment of Karsten which is very remarkable, and deserves particular attention: it is, the very large proportion of combined carbon in the iron after the treatment by sulphur. In the experiments previously recorded, in which the conditions were favourable to the production of cast-iron containing the maximum of carbon, this element appeared to exist in the solidified iron almost wholly as graphite. This fact, according to my experience, cannot be explained by assuming extreme rapidity of cooling, about which nothing is stated. The question which naturally suggests itself is, whether sulphur in certain proportions has the power of causing carbon to remain in the combined state during solidification after fusion?

M. Janoyer published a paper on the direct action of sulphur on cast-iron,[8] in which he states that there had been no prior announcement in

[7] Vid. Handb. der Eisenhüttenk., Karsten, 1, p. 427. 1841.

[8] Recherches sur l'influence du Soufre sur la nature des Fontes. Par M. Janoyer. Ann. des Mines, 4. s. 20, pp. 359-378. 1851.

any metallurgical work concerning "the mode of action of sulphur" in cases such as he had been led to investigate. This statement would seem to indicate entire ignorance of the labours of his predecessor, Karsten, and forgetfulness on the part of the Editors of the Journal named in the reference at the bottom of the previous page. Janoyer melted grey iron with small proportions of iron-pyrites, and satisfied himself that there was a loss of carbon, due to the formation and volatilization of bisulphide of carbon. The grey iron, upon which he operated, contained 0·09 % of sulphur. In one experiment this iron was melted with 2 %, and in another with 1 % of iron pyrites. "When fusion had occurred, the crucible was uncovered; the molten mass was found to be very liquid, and brilliant globules, more intensely white than this mass, were disengaged between the sides of the crucible and the metallic button, but disappeared in contact with the air, causing at this point a very notable lowering of the temperature. After the disengagement had ceased, the metal in the crucible was very slowly cooled, in order to be sure that its whiteness might not be the result of cooling too quickly. In spite of this precaution, the cast-iron, which until then had remained tranquil and smooth on the surface, split actively in all directions with loud decrepitation, and became covered with a wrinkled crust, which partially separated from the metal and presented in all respects the characters of a granular cast-iron, such as proceeds from incomplete carburization in a badly-working furnace. On fracture, the metal in both these experiments was white, and the whiteness was proportionate to the iron-pyrites employed; it was excessively hard, and could not be touched with a file of cast-steel." That from the first experiment contained 0·87 % of sulphur, showing a loss of 0·28 %; and that from the second experiment contained 0·46 % of sulphur, showing a loss of 0·16 %. No mention is made of the separation of pulverulent carbon, and the experiments were clearly vitiated by uncovering the crucibles and exposing the molten contents to the action of the air.

Janoyer then repeated the experiments of Berthier, which demonstrate that there is no loss of sulphur when clean iron filings are melted with iron-pyrites. "In order to avoid slight oxidation by the air which might find its way into the crucible," says Janoyer, "I covered it with a piece of coke. When the whole mass had been heated to welding whiteness, I uncovered the crucible in order to see if, in this case, as in that of melting cast-iron with 3 % of iron-pyrites, there was disengagement of brilliant globules. I saw no disengagement; the mass remained tranquil; when cold, it had the form of a compact, thoroughly welded button (très bien soudé); when broken, one perceived here and there sulphide of iron of a tolerably dark brown-yellow colour, which doubtless was only the protosulphide disseminated in the mass." There is an obvious source of error in this experiment, due to the contact of the coke. This first trial satisfied Janoyer of the formation of bisulphide of carbon, when grey iron is melted in contact with iron pyrites, "because in this case only," he states, "I remarked the disengagement of brilliant globules." The

formation of bisulphide of carbon may be very probable under these conditions; but it is not established upon evidence like that which appears to have satisfied Janoyer.

Other experiments were made by Janoyer to prove that white iron is formed when iron ores, such as brown hæmatite, are reduced in crucibles in admixture with iron pyrites, lime, and carbon; and that whiteness is caused by the presence of sulphur in the metal. But every person experienced in assaying iron ores by the *dry way*, knew this fact perfectly well. Janoyer found that in the blast-furnace on the large scale, when the ore contained a sensible quantity of pyrites, he could not produce good grey iron by increasing the proportion of lime, employed as a flux, to the maximum that could be used, which he ascertained from his own trials to be expressed by 54 % of lime in the slag, the alumina amounting to 10 %, and the silica to 36 %. The sulphur in the cast-iron was found to diminish in proportion to the amount of lime introduced into the furnace, *cæteris paribus;* but it was impossible to add sufficient lime to effect complete desulphurization of the iron, and at the same time produce a fusible slag.

Janoyer in part attributes the formation of white iron, when sulphur is present, to the diminished temperature of the furnace, consequent on the production and volatilization of bisulphide of carbon, by which "a very great quantity of heat becomes latent." When there is such an adequate *vera causa* at hand as the presence of sulphur in the cast-iron, we may well be satisfied without this theory about latent heat. Janoyer is a little puzzled to account for the fact of the absence of bisulphide of carbon from the gases escaping from blast-furnaces; but the difficulty vanishes when he reflects that bisulphide of carbon cannot exist at high temperatures in contact with oxide of iron. Consequently, as its vapour ascends in the furnace, it is decomposed by the oxide of iron of the ore, forming sulphide of iron and carbonic oxide; and so the sulphur actually passes back again into the iron. The notion may be ingenious, but is hardly plausible. Speculations with reference to the metallurgy of iron abound, but we are now in urgent need of facts.

The following experiments on the action of sulphur on grey iron have been made in my laboratory by Mr. Smith:—

1. 3050 grains of grey pig-iron were melted in a clay crucible under plate-glass with 95 grs. of sulphide of iron containing 29·9 % of sulphur. The iron was covered with black glass, and between the two was a very small quantity of soot-like matter. The fracture of the metal was uneven, minutely granular, and dark grey. Supposing no loss of sulphur to have taken place, the metal should have contained 0·9 %.

2. The experiment was repeated with 8800 grs. of the same grey iron and 870 of the same sulphide. The crucible, which was covered and luted, was kept at white heat during 1½ hour. Between the layer of glass covering the lump of metal and the latter was found a considerable quantity of more or less pulverulent and loosely aggregated black matter, which had much the colour, lustre, and form of graphite.

The crucible was perfectly closed, and not a crack was visible either in it or the cover, so that nothing could have fallen in. The metal had the appearance of white iron, was brittle, and excessively hard. The centre of the lump was more or less hollow, and round this hollow there were distinct skeleton-like crystals. The fracture was uneven, and somewhat lamellar in structure. The metal contained 0·78 % of sulphur; but, if no loss had occurred, should have contained 2·68 %.

3. Some of the coarsely-pounded white iron produced in Exp. 2 was mixed with a large excess of common charcoal powder, and exposed in a plumbago crucible during 1½ hour to a temperature sufficient to melt wrought iron. After cooling, the charcoal in excess was separated from the shots of metal by washing with water. On fracture, the metal appeared to consist of small rounded particles of grey iron enclosed in a network of white iron, thus producing mottling. The fracture exactly resembled that of a specimen of pig-iron which Mr. C. Ekman has sent me from Finspong, which is known to contain sulphur, and is regarded as very suitable for ordnance. The greater part of the metal was remelted under charcoal into a button. The fracture of this was similar to that just described, except towards the upper part, which contained numerous bright and seemingly graphitic scales, and the white network was more attenuated, or, in other words, the amount of metal forming this network appeared less abundant than before remelting. The product of the second fusion contained 0·34 % of sulphur. Two determinations were made, one giving 0·33 %, and the other 0·35 %.

4. 10,600 grs. of another variety of grey pig-iron were melted during about an hour in a clay crucible under plate-glass, with 327 grs. of the same sulphide of iron as used in the preceding experiments. A considerable quantity of graphite-like matter was interposed between the layer of black glass covering the metal and the upper surface of the latter.

The metal contained 0·091 % of sulphur. Two determinations were made by different persons; one gave 0·094 %, and the other 0·088. Supposing no loss of sulphur to have occurred, there should have been 0·903 %. Hence, 0·815 % of sulphur escaped. The metal was prepared for analysis by filing, as it could not be pulverized.

The graphite-like matter was digested with aqueous hydrofluoric acid, when a large quantity of sulphuretted hydrogen was evolved, and hydrogen also, having a peculiar odour, which could be perceived long after that of sulphuretted hydrogen had ceased. The residue was next treated with a mixture of hydrochloric and hydrofluoric acids; well washed, and boiled with solution of caustic soda. To this solution excess of hydrochloric acid was added; it became turbid, and yellowish white, exactly as is the case when sulphur is precipitated. Portions of slag-like matter, which remained insoluble in the acid solutions above employed, were finely pounded, and again treated with the same mixture of acids. A large quantity of iron was dissolved out, and the graphite-like matter left undissolved was added to that

first obtained. It was very bulky, and when dry weighed 14·0 grains. Still, it was not pure; 3·479 grs. of it heated in a muffle on platinum yielded not less than 1·03 of brown residue. This was digested with hydrochloric acid, evaporated to dryness, redigested with hydrochloric acid, and filtered. The residue, which weighed 0·182 gr., was treated with hydrofluoric acid, which dissolved only very little, and was afterwards fused with carbonate of soda. The mass was treated with hydrochloric acid in the usual manner, and the filtrate contained iron with traces of alumina, which, weighed as sesquioxide, amounted to 0·819 gr.; 0·182 + 0·819 = 1·001; so that the residue left by incineration, which weighed 1·03 gr., consisted chiefly of sesquioxide of iron.

5. 1540 grs. of grey pig-iron (about No. 2 in greyness) were melted in a clay crucible *under a plug of charcoal* with 90 grs. of the same sulphide as used in the preceding experiments. Graphite-like matter accumulated on the top of the button of metal, which was white throughout and could be pulverized. The metal contained 1·13 % of sulphur; but if there had been no loss, it should have contained 1·65 %.

6. Grey pig-iron was melted in a clay crucible under plate glass at the highest temperature attainable in our air-furnaces, and in all respects the conditions were the same as in the preceding experiments. The fracture was dark grey, and there was no indication of white iron.

In the succeeding experiments, which were made in my laboratory by Mr. W. Weston, cast-iron was expressly prepared by exposing thin sheet-iron imbedded in chemically pure charcoal to a very high temperature. The metal was highly graphitic, and contained 4·5 % of carbon. The same sulphide of iron which was used in the preceding experiments was employed as the source of sulphur. The total carbon was determined by combustion with chromate of lead in a current of oxygen, as is usual in ultimate organic analyses.

7. Sulphur added, 4·378 %. 376 grs. of the cast-iron were melted with 64·5 grs. of sulphide. White iron was produced, but without separation of graphite. The metal contained 2·12 % of sulphur; but, if there had been no loss, it should have contained 4·378 %. The total carbon amounted to 3·17 %.

8. Sulphur added, 2·235 %. 359 grs. of this cast iron were melted during about half an hour with 29 grs. of sulphide. The button consisted of very crystalline white iron, and graphite had separated; the loss was 3·4 grs. The metal contained 1·68 % of sulphur; but, if there had been no loss, it should have contained 2·235 %. The total carbon amounted to 3·9 %, and of this 1·44 consisted of graphitic carbon, as determined by an analysis with hydrochloric and hydrofluoric acids, etc. Consequently, the combined carbon was 2·46 %.

9. Sulphur added, 1·243 %. 415 grs. of the cast-iron were melted with 18 grs. of sulphide. White iron was produced with the separation of graphite; the loss was 1 gr. The metal contained 1·313 % of sulphur; but it should have contained 1·243 %; so that there is a

slight excess, which proves that there must have been an error in the determination. The total carbon amounted to 3·6 %.

10. Sulphur added, 0·696 %. 302 grs. of the cast-iron were melted with 7·2 of sulphide; some graphite separated. The metal, however, was not white, but grey, with a network of white, as previously described. It contained 0·72 % of sulphur; but, if there had been no loss, it should have contained 0·696 %. Carbon not determined.

For the sake of convenience, Weston's results are presented in the following tabular form:—

No.	Percentage of carbon and sulphur.						Relation between carbon and sulphur in the product.		Quality of the iron produced.
	Before experiment.		After experiment.		Loss in the experiment.				
	Carbon.	Sulphur.	Carbon.	Sulphur.	Carbon.	Sulphur.	Carbon.	Sulphur.	
7	3·841	4·378	3·170	2·120	0·670	2·258	6	20·22, or $C^4:S^5$	White, no graphite.
8	4·164	2·235	3·900*	1·680	0·264	0·555	6	12·58, or $C^4.S^3$	White, graphite separated.
9	4·313	1·243	3·600	1·313(?)	0·713				Do. do.
10	4·395	0·696	not determ.	0·720	not determ.				Mottled, do.

* Of this 1·44 was graphite.

In No. 8, 2·46 of combined carbon : 1·68 of sulphur : : 6 : 4, *i.e.*, in the ratio $C^4 : S$; and 1·44 of graphitic carbon : 1·68 of sulphur : : 6 : 7, *i.e.*, as $C^5 : S^2$, nearly. Hence, these experiments do not indicate the formation and volatilization of bisulphide of carbon (CS^2); yet it is far from my intention to suggest that such a small number of results should be received as conclusive evidence. That there is loss of sulphur due to the action of carbon is certain, if these experiments be, as I believe them to be, correct. Yet the contrary is maintained by Karsten, who thus writes: "According to my repeated experiments, sulphide of iron with the minimum of sulphur remains perfectly unchanged when kept with carbon at the strongest white heat during an hour; but it takes up some carbon, and becomes thereby brittle."[9] On the other hand, Fournet, whom Karsten quotes, asserts that sulphide of iron is decomposed in the presence of charcoal, when long enough exposed to a high temperature, and that the iron combines with carbon, forming cast-iron, which separates pretty completely when in sufficient quantity.[1] So the matter must rest until further experiments determine on which side lies the truth. One point of interest in Weston's results is, that when the sulphur in cast-iron amounts to about 2¼ %, the coexistence of graphite is impossible, and the metal is necessarily white. How much smaller proportion of sulphur may produce this effect has yet to be ascertained.

According to recent experiments by Caron, metallic manganese by simple fusion with cast-iron deprives the latter in great measure of sulphur.[2] Cast-iron as pure as possible was directly prepared by melting iron of a very good quality with wood-charcoal. This was

[9] Eisenhüttenkunde, 1, p. 429.

[1] Ann. des Mines, 3. s. 4, p. 244. 1833.

[2] Comptes Rend. 56, p. 828. Avril, 1863.

fused with sulphide of iron in such proportion that the product contained 1·15% of sulphur. Two equal quantities of this cast-iron were placed in two crucibles, one without the addition of anything, and the other with 6% of so-called metallic manganese, which on analysis was found to contain 5·5% of carbon, 0·5% of silicium, and 1·0% of iron. The metal was kept in a molten state during an hour and then poured out, during which some oxidation due to the access of atmospheric oxygen must have taken place. Caron records his results as follows:

	For 100 of cast-iron.	
	Sulphur.	Manganese.
Sulphurized cast-iron (A)	1·15	
No. 1. do. do. remelted alone	1·14	
No. 2. do. do. remelted with 6% of manganese	1·15	3·92
No. 1. Second fusion without addition	1·05	
No. 2. do. do.	0·10	2·81
No. 1. Third fusion without addition	0·96	
No. 2. do. do.	0·08	1·73
(A) remelted with 10% of sesquioxide of iron	1·08	
(A) remelted with 10% of sesquioxide of iron and 6% of manganese	0·07	1·22

Hence, by simple fusion in a crucible with access of air, manganese abstracts from cast-iron more than 0·7 of the sulphur which it contains. After remelting the fused products with a fresh dose of manganese, only traces of sulphur remained. It would appear that the manganese acts as a medium through which the sulphur is oxidized and eliminated in the state of sulphurous acid. Caron, however, concludes that without any such oxidizing action, sulphur disappears from cast-iron in the presence of manganese; but this conclusion seems hardly justified by the *data* from which it is drawn. I think it would be difficult, under the conditions described by Caron, to keep the alloy of cast-iron and manganese melted during an hour without oxidation. In favour of his view concerning the desulphurizing action of manganese, Caron cites the fact that certain iron ores, impregnated with copper pyrites, yield pig-iron free from sulphur, because they are highly manganesiferous. These ores, however, are very carefully calcined previously to smelting, whereby most of the sulphur is expelled; and if the presence of manganese were really the cause of the absence of sulphur from the pig-iron, its action must be entirely different in the blast-furnace from what is ascribed to it in the foregoing experiments, and may, probably, be explained by the observation of Mr. Parry before recorded.

On the action of phosphorus on iron containing carbon and sulphur.—Janoyer has sought to establish, by the following experiments, that phosphorus expels a portion of sulphur from iron containing carbon:[3]—

1. 3grm·5 of fine very graphitic pig-iron was melted in an unbrasqued clay crucible with 0grm 14 of iron-pyrites. A well-melted button of perfectly white iron was obtained. It bent tolerably well under the hammer, although he describes it as consisting "only of filamentous crystallizations of protosulphide of iron (ce n'était qu'un amas de cris-

[3] Ann. des Mines, 5. s. 6, p. 158. 1854.

tallisations filamenteuses de protosulfure de fer)." It had a dull aspect, was difficultly pulverizable in a mortar, and flattened into small scales. Certain parts of it especially were very ductile; and these he regarded as iron in a free state which had been mechanically mixed with protosulphide. It contained 1·714 % of sulphur.

2. $3^{grm.}5$ of the same pig-iron was melted in a similar manner with $0^{grm.}14$ of iron-pyrites, $0^{grm.}14$ of calcined bones, and $0^{grm.}09$ of white refractory clay. A well-melted button of perfectly white iron was obtained. It was very brittle, easily pulverizable by trituration in a mortar, and did not bend in the least under the hammer. Under a lens it was easy to distinguish portions "with sulphureous crystallizations placed at right angles, and crystalline portions with very bright facets." It contained 1·486 % of sulphur, *i.e.*, 0·228 % less than the button in the first experiment. Janoyer attributes this loss of sulphur to the action of carbon, and supposes that it escapes in the state of bisulphide of carbon. He explains on this principle, how the introduction into the blast-furnace of ore containing a sensible amount of phosphorus may tend to counteract red-shortness due to sulphur in the pig-iron, which otherwise might be produced; or, in other words, sulphur is eliminated in a greater or less degree from iron by the action of carbon. He records the results of his experience in the smelting of iron, and states, that by the addition of oölitic ore, containing not more than 0·2 % of phosphoric acid, in the proportion of 0·106 of phosphorus to 240·0 of the pig-iron made, he obtained pig-iron which yielded bar-iron practically free from red-shortness; whereas, without this addition, the pig-iron, though produced from a fine quality of red hæmatite free both from sulphur and phosphorus, always yielded red-short bar-iron. He satisfied himself that the red-shortness was not caused in the subsequent processes of manufacture, as the pig-iron made without and with the addition of phosphoric ore was converted into bar-iron in exactly the same way and with the same fuel. Moreover, the smelting was conducted under the same conditions, with the single exception that in one case phosphoric ore was used, but not in sufficient quantity to occasion cold-shortness.

Other experiments were made by Janoyer, which demonstrated that sulphur expels no phosphorus from iron in the presence of carbon.

1. 5 grammes of grey pig-iron were melted with $0^{grm.}20$ of iron-pyrites, $0^{grm}\,20$ of calcined bones, and $0^{grm.}20$ of clay.

2. 5 grammes of the same pig-iron were melted with $0^{grm}\,20$ of calcined bones, and $0^{grm.}20$ of clay.

The button in each case contained the same proportion of phosphorus.

Janoyer in recommending phosphoric ores with a view to counteract red-shortness very wisely enjoins moderation in their use. The following passages in Janoyer's paper on this subject require comment. "It has been remarked, in ignorance of the true cause, that crystalline irons (fers à facettes), though brittle while cold, may be very easily forged." If I do not greatly err, metallurgists were acquainted both with the fact and the explanation long before the date of the paper in

question; and they were also aware "that traces of sulphur suffice to communicate injurious properties to iron, and to render it red-short." Neither were they ignorant "that the passage of sulphur into iron in general chiefly takes place during fusion of the ore in contact with mineral fuel in the blast-furnace, and that, consequently, it is in this operation they should try to prevent the evil."

Caron ascertained that manganese has no power of eliminating phosphorus from cast-iron, as it has with respect to sulphur. He made a series of experiments upon phosphorized iron exactly similar to those recorded upon sulphurized cast-iron.[4]

Spiegeleisen heated with silica.—The following experiment has been made in my laboratory by Mr. Hochstätter. Of characteristic German spiegeleisen, containing 5·39 % of manganese and 0·37 % of silicon, 1500 grains in powder were mixed with 300 grains of fine white sand. The mixture was kept at a white heat during about 1 hour in a covered clay crucible contained within another. The product was well melted, and weighed 1460 grains. It was covered with a little well melted slag. It was very slightly malleable. Its fracture was peculiar, and it is difficult to give an accurate notion of it by description. It was what may be termed fibro-columnar. It was very dark-grey, and, with the exception of brilliant points here and there, was dull and non-metallic in lustre; but on burnishing it immediately appeared bright and metallic. On remelting a piece of this metal under charcoal in a covered clay crucible, the product was unchanged in external aspect, except that it was no longer columnar. After long digestion in strong hydrochloric acid, a light, bulky, black residue was left, which consisted of carbonaceous and siliceous matter. This residue was boiled with a solution of caustic potash, when a colourless solution was produced, thus showing that no carbonaceous matter had been dissolved; and there was an insoluble black light residue, which was washed and dried at 100° C. From the weight found, it was calculated that the total amount in the original lump of metal was 7·6 %. The first product was composed as follows:

Graphite	1·61
Silicon	2·91
Manganese	0·99
Iron, by loss	94·49
	100·00

There may, possibly, have been present a little combined carbon, evolved along with the hydrogen by the action of hydrochloric acid; but if the carbon in this state had been considerable, the solution in potash would have had a brown colour. Hence, it may be inferred that by the action of silica on spiegeleisen at a high temperature, the manganese is for the most part converted into protoxide, which combines with silica to form slag, and that most of the carbon is separated in the form of graphite, being replaced by silicon.

[4] Op. cit.

On the action of copper on iron and manganese containing combined carbon.—The following experiments were made in my laboratory by Mr. Richardson. Electrotype copper and a fine and characteristic quality of spiegeleisen, containing 8 % of manganese, were operated on.

1. Weights employed. Spiegeleisen 704·2 grains.
Copper 342·6 do.

These were placed in a small clay crucible, enclosed in one of plumbago, each having a well luted cover, and exposed to a high temperature during 1½ hour. The product had been well melted, and presented the following characters:—

A core of apparently unchanged spiegeleisen; an external layer about ⅛ in. thick, resembling grey iron. Near the foot of the unchanged spiegeleisen were several small spots of the same substance; and a very pale coloured copper, a thin layer of which extended over the surface.

In a cavity on one side of the button some graphite had separated. After removing this the lump of metal was weighed, and the loss found to amount to 5·8 grains. The coppery part of the lump contained 2·82 % of manganese, and 4·87 % of iron.

The core of apparently unchanged spiegeleisen presented no visible trace of copper on the fractured surface, but contained 2·50 % of copper.

2. Weights employed. Spiegeleisen 500 grains.
Copper 500 do.

Fusion was effected as in the first experiment. The product had been well melted, and presented the same characters as that of No. 1, except that its surface was covered with graphite. After the removal of this the lump was weighed, and the loss found to amount to 3·4 grains. The coppery part of the lump contained 1·16 % of manganese and 3·67 % of iron.

3. Weights employed. Spiegeleisen 334·00 grains.
Copper 666·45 do.

Fusion was effected, and the lump of metal presented almost the same characters as in the previous experiments. A small quantity of graphite had separated on the surface. After the removal of this the loss in weight amounted to 2·35.

In Experiments 2 and 3 the proportion of copper in the residual spiegeleisen could not be determined on account of the impossibility of freeing it from mechanically mixed copper.

The results may thus be concisely stated: Spiegeleisen containing 8 % of manganese by fusion with half its weight of copper lost 1·16 % of manganese; and by fusion with an equal weight of copper it lost 1·34 %. The separation of graphite is an interesting fact.

On the abstraction of silicon from cast-iron by fusion with sesquioxide of iron alone, and with the addition of manganese.—The following experiments

have been made by Caron.[5] Cast-iron containing 0·99% of silicon was operated upon.

PROPORTIONS PER CENT.

		Sesquioxide of iron.	Metallic manganese.	Silicon in the product.	Manganese.
1st Fusion	a	10	none	0·61	–
	b	10	6	0·37	2·52
2nd Fusion.........	a	10	none	0·52	–
	b	10	none	0·18	1·07

It would thus appear that in the presence of manganese, sesquioxide of iron has the power of separating silicon from cast-iron, silicate of protoxide of manganese being formed.

On the fusion of cast-iron containing sulphur with cast-iron containing phosphorus, without and with the addition of manganese.—Experiments have also been made by Caron on this subject.[6] He prepared expressly two specimens of cast-iron, of which one contained 1·04% of sulphur, and the other 0·85% of phosphorus. Equal weights of each were melted together and poured into ingot-moulds. The product contained 0·51% of sulphur, and 0·42% of phosphorus. The product, after having been remelted with the addition of sesquioxide of iron, contained 0·49% of sulphur, and 0·40% of phosphorus. It was again remelted with the addition of 6% of metallic manganese, when it retained only 0·15% of sulphur, and 0·39% of phosphorus. Hence, Caron concludes that by simply melting together cast-irons containing sulphur and phosphorus, there is no diminution in the proportion of these elements.

Carbonate of protoxide of iron. FeO, CO^2.—This salt occurs abundantly in nature, and is found in geological formations of nearly every age. It is one of the most important ores of iron, and should therefore be particularly studied by the metallurgist. It crystallizes, like calc-spar, in the rhombohedral system, and then constitutes the mineral species termed *sparry* or *spathic iron-ore*, which always contains carbonate of protoxide of manganese, and generally also carbonate of lime and magnesia. It is met with in crystals more or less translucent, having a vitreous lustre inclining to pearly, and a yellowish-white colour; but most frequently it is brown, owing to partial decomposition by weathering action, hydrated sesquioxide of iron being formed, and an equivalent proportion of carbonic acid evolved. The specific gravity of the native crystallized varieties ranges from 3·70 to 3·92. The native salt, whether crystallized or amorphous, is anhydrous. Sénarmont obtained this salt as a crystalline greyish-white sand, which was hardly attacked by dilute acids, remained nearly unchanged in dry air, and very slowly acquired a pale-brown colour in moist air. It was made by exposing a mixture of sulphate of protoxide of iron and carbonate of soda, or of protochloride of iron and carbonate of lime, in hermetically-sealed glass tubes, to high temperatures, the former to a temperature of 150° C. or beyond, and the latter to

[5] Op. cit. [6] Comptes Rendus, 1863. 56, p. 1017.

temperatures between 130° C. and 200° C., during from 12 to 36 hours.[7] The salt was darker in colour, and more permanent in the air, the higher and the longer the duration of the temperature employed. The form of the crystalline grains was distinctly rhombohedral. The crystallized salt dissolves but slowly in dilute hydrochloric acid. The addition of carbonate or bicarbonate of potash or soda to a solution of a protosalt of iron, such as the protochloride or sulphate of protoxide, causes a bulky white precipitate of hydrated basic carbonate of protoxide of iron, which rapidly absorbs oxygen from the air, becoming first green and afterwards brown. It is completely and pretty quickly converted, by exposure to the air, into hydrated sesquioxide. In order to prepare it artificially, the greatest precautions must be taken to exclude air at every step of the process. The solution of the alkaline precipitant should be well boiled, and that of the salt of iron should be perfectly free from any persalt; and the washing and desiccation should be effected in an atmosphere of carbonic acid. Thus prepared it is a greenish-white or dark-green powder containing water and from 24 °/₀ to 3°/₀ of carbonic acid.[8] Carbonate of protoxide of iron is slightly soluble in water, and more so by the aid of carbonic acid; and it occurs thus dissolved in chalybeate waters, which in contact with the air let fall a brown precipitate of hydrated sesquioxide of iron, owing to the decomposition of the carbonate in the manner previously explained. Iron dissolves, without access of air, in water impregnated with carbonic acid, when carbonate of protoxide is formed, which remains, in a greater or less degree, in solution. Water is decomposed, hydrogen evolved, and the reaction is exactly analogous to that of dilute sulphuric acid on iron. The *action of heat* upon solid anhydrous carbonate of protoxide of iron should be noted. When heated to redness in a close vessel, carbonic oxide as well as carbonic acid is given off, and the residue is magnetic. It is stated that the volumes of these gases are in the ratio of 1 : 5, and that the composition of the residual oxide is represented by the formula $4FeO, Fe^2O^3$. Hydrate of potash, aided by a pretty strong heat, abstracts carbonic acid from carbonate of protoxide of iron; carbonate of potash, magnetic oxide of iron, and carbonic oxide are formed, which escapes.[9]

Carbonate of sesquioxide of iron. $Fe^2O^3, CO^2+aq.$—This compound, which was formerly not believed to exist, has been recently investigated by several observers. The most conclusive experiments on the subject appear to be those of Dr. Parkman.[1] He prepared it by the addition of carbonate of soda in slight excess to a solution of pure crystallized iron-potash-alum at the ordinary temperature. The precipitate was not washed or dried, but simply pressed between folds of porous paper, under a heavy weight, for about 12 hours; and while still moist introduced into a bulbed tube of hard glass, and the whole weighed. It was then ignited in a slow stream of dry air, and the

[7] Ann. de Chim. et de Phys. 3. s. 39, p. 135. 1850.
[8] Gmelin, Handb. 5, p. 221.
[9] Glasson, L. u. K. Jahresb. 1847-1848. p. 443.
[1] American Journ. of Science and Arts, 34, p. 321. 1862.

water caught by a weighed chloride of calcium tube. The carbonic acid was estimated by loss. It was therefore only the relation between the acid and base that was ascertained. Three specimens were thus analysed, and in one instance twice, and the results closely agree. The calculated percentage is Fe^2O^3 78·43, and CO^2 21·57; and the mean percentage of four analyses was Fe^2O^3 79·74, and CO^2 20·26. This carbonate is decomposed by washing with water, by drying *in vacuo* over sulphuric acid, and on standing.

Iron and Hydrogen.

A compound of iron and hydrogen has been described by Wanklyn and L. Carius.[1] It is prepared by the action of protoiodide of iron on zinc-ethyle, the other products being iodide of zinc and ethylene gas. The following formula expresses the reaction:—

$$Fe^2I^2 + Zn^2(C^4H^5)^2 = Zn^2I^2 + Fe^2H^2 + 2(C^4H^4).$$

It is described as a black powder resembling metallic iron, which evolves pure hydrogen when gently heated. Protected from moisture, it may be kept without change; but on the addition of water pure hydrogen is immediately disengaged, and protoxide of iron formed. Hydrochloric acid decomposes it, with the liberation of hydrogen and the production of protochloride of iron. Its composition has not been satisfactorily determined.

The Action of Dilute Sulphuric, or Hydrochloric Acid, on Cast-iron.

White cast-iron.—When this variety of cast-iron is subjected to the solvent action of dilute sulphuric, or hydrochloric acid, fetid hydrogen is evolved, and a light insoluble residue, which is dark-brown while moist and light-brown when dry, is obtained. The products of this action have not yet been investigated, although they present a promising field of research, especially for the so-called organic chemists.

The peculiar odour of the hydrogen has been supposed mainly to depend upon the presence of a hydrocarbon. I have made a few experiments on the subject, which I will here record in the hope of inducing some chemist to prosecute the enquiry as it deserves. Schrötter found that on passing the hydrogen through sulphuric acid, a dark-brown oily substance was retained, of which, I believe, he never procured more than a few drops. I have prepared an ounce or two of this substance according to Schrötter's method by the action of dilute sulphuric acid on spiegeleisen, applying when necessary gentle heat. The operation was continued during many days, and in all I dissolved about 12 lbs. of spiegeleisen. The sulphuric acid became brown, and exhibited the same optical appearance as an aqueous solution of disulphate of quinine or of chestnut bark; it had a strong and characteristic odour, much resembling that of petroleum. In the course of a

[1] Ann. de Chim. et de Phys. 3. s. 64, p. 483. 1862.

few days after the passing of the gas an oil-like liquid of a light-brown colour separated and appeared on the surface of the acid. When the acid appeared to be saturated it was poured off, and replaced by fresh acid. A considerable quantity of this oil was prepared and kept by itself. The brown acid from time to time was gradually poured into a large volume of cold water in a beaker surrounded by cold water. A muddy light-brown liquid was formed, which, after standing for about 12 hours, became clear, a stratum of dark-coloured oil collecting on the surface, and the acid liquor underneath having a deep brownish pink-red colour. This liquor was drawn off by a syphon, and the supernatant oil collected, and so the process was conducted.

The oil.—When seen in small quantity, its colour is dark-greenish brown. Its odour somewhat resembles that of petroleum; and it also evolves the odour of sulphurous acid, which it loses by the addition of carbonate of soda. It burns with a luminous smoky flame. It immediately dissolves in cold ether, forming a dark-brown solution; but it does not sensibly dissolve in cold alcohol. Some light-brown flocculent matter, possibly a product of oxidation, was diffused through the oil, as, in the process of collecting the oil, the air had free access. A few drops of the oil on glass having been left exposed to the air, became sticky and apparently resinoid.

In addition to the light-brown oil a considerable quantity of a thick black oil is produced, from which, by the addition of sulphuric acid, nearly colourless oil comes to the surface on standing. The dark oil burns with a smoky flame.

The light oil being mixed with a little carbonate of soda was subjected to fractional distillation in a current of carbonic acid, and several limpid and colourless products, having boiling points ranging from 200° C. to 270° and upwards, were obtained. These products had peculiar odours. That which passed over last was analysed by Mr. Tookey, and found to be isomeric with olefiant gas. It is probable that the hydrocarbon or hydrocarbons generated from the spiegeleisen may have been decomposed by the action of the sulphuric acid. A portion was not distilled over, and this was pale yellow, and oily in consistency, resembling olive oil in appearance.

I passed the gas through absolute alcohol, which acquired an offensive odour like that of the gas, but no sensible amount of oil was retained. I also passed the gas through a glass tube surrounded with a mixture of pounded ice and dilute sulphuric acid without succeeding in condensing any sensible quantity.

The insoluble residue.—When dry it is bulky, extremely light, of a greyish brown colour, and evolves a peculiar odour. Gently heated in a test tube, white vapour is produced, which condenses in oily drops. The matter forming the residue takes fire at a low temperature, and burns like tinder. Boiled with a solution of potash, a brown liquid is obtained, having a peculiar odour, and from which brown flocculent matter is precipitated by the addition of an acid in excess. This matter, after washing and drying, is dark-brown and bright.

Grey cast-iron.—The insoluble residue obtained by the action of dilute sulphuric or hydrochloric acid on this variety of cast-iron for the most part consists of graphite; and there is reason to believe that crystallized silicon may also not unfrequently be present, this element being separated during solidification like carbon, or as it separates during the solidification of zinc in Deville's process for its preparation. Richter of Leoben has described the occurrence of scales of crystallized silicon in a specimen of pig-iron in octahedral crystals; it was found in the insoluble residue left by the action of hydrochloric acid.[3] I have previously mentioned the fact that the late Mr. T. H. Henry informed me that he had found crystallized silicon amongst the graphitic scales in the residue obtained by the action of hydrochloric acid on pig-iron. Some time ago beautiful specimens of graphite in large plates were forwarded to me from the Dowlais Iron-works by Mr. W. Child, my former pupil, now chemist there. I digested a portion in hydrochloric acid during a considerable time, when some lumps, apparently of slaggy matter, remained insoluble along with the graphite. The residue was well washed with water, dried, and put into molten potash in a gold crucible; much effervescence took place, due to the evolution of gas, which ignited at the surface just like hydrogen. Successive portions of potass were added, and the mass kept melted until gas ceased to be disengaged. When native graphite was similarly treated there was not the slightest effervescence. I regarded the action above described as most probably caused by the presence of free silicon.

In 1817 the late Professor Daniell published a paper on 'The Mechanical Structure of Iron developed by Solution, and on the Combinations of Silex in Cast-Iron.'[4] A cube of grey cast-iron was immersed in dilute hydrochloric acid; and when the acid was saturated, the cube was taken out and examined. It did not appear to have diminished in volume, and consisted of a soft spongy substance. A specimen of white cast-iron, of a radiated fracture, was similarly acted upon, and it required three times as long to saturate the acid as in the case of the grey cast-iron. The spongy mass from this metal was easily cut with a knife; it was dark grey, somewhat resembling plumbago; some of it was put to dry on blotting-paper, and in the course of a minute it spontaneously heated and smoked. In one instance, when a considerable quantity of it had been heaped together, it ignited, and scorched the paper. Its properties were not impaired by being left for days and weeks in the solution of iron, or in water. Some of it, which had been left during three months covered with a solution of sulphate of iron, freely exposed in an open dish, raised the thermometer 20° when collected on blotting paper. It absorbed oxygen and became very hot, but without changing in appearance. Exposed to chlorine, it also became much heated, and a yellow liquid formed. Some of it, after having been thoroughly digested in hydrochloric acid, and washed, etc., was heated to low redness with 200 grains of pure

[3] Berg- und Hüttenmännisches Jahrbuch. 1862. 11. p. 288.

[4] The Journal of Science and the Arts. 2. p. 278.

soda in a silver crucible. A puff of gas occurred, and the crucible was instantly removed from the fire. The product was treated with water. The insoluble residue, digested in hydrochloric acid, washed, and dried, resembled micaceous iron ore in appearance. The aqueous solution saturated with hydrochloric acid and evaporated, gelatinized, and characteristic silica was left.

Calvert has examined the residue produced by the uninterrupted action during two years of dilute hydrochloric acid or acetic acid on cubes of grey cast-iron. It weighed about 22 % of the original metal. When exposed to the air it quickly becomes hot, owing, according to Calvert, to the oxidation of the iron which it contains. The following analyses of the cast-iron and residue are given:[5]—

	Cast-iron.	Residue.
Carbon	2·900	11·020
Nitrogen	0·790	2·590
Silicon	0·478	6·070
Iron	95·413	79·960
Sulphur	0·179	0·096
Phosphorus	0·132	0·059
Loss	0·108	0·205
	100·000	100·000

This residue has not, as yet, been satisfactorily investigated.

Action of Sea-Water on Cast-Iron.

When pig-iron has been long exposed to the action of sea-water, a grey spongy light mass is obtained. I have a specimen of this kind, which formed part of a cannon-ball dredged up in Falmouth Harbour, where, it was supposed, the ball had lain during many years. In ancient bloomery slags I have found globules of metal replaced by similar matter. This change is perfectly well known.

Fifty years after the sinking of a vessel of war near Carlscrona, the cast-iron guns, with which it had been armed, were got up, and found to be changed to the extent of one-third into a grey, porous, graphitic mass; and after exposure to the air for a quarter of an hour, they became so hot that the water, with which they were impregnated, was converted into steam, and it was impossible to touch them. Berzelius, who is the authority for the foregoing statement, supposed that the iron was gradually converted into carbonate by the conjoint action of the oxygen and carbonic acid on the water, and so dissolved away.[6] Mr. Wilkinson has collected and recorded the following similar cases.[7] Many of the vessels of the Spanish Armada were sunk off the shore of Mull, in Scotland; and in 1740 some of the guns of one of these vessels, named the "Florida," were raised. There were both "brass" and cast-iron guns; and on scraping the latter, which were deeply corroded, they became so hot that they could not be touched. However, they lost this property after 2 or 3 hours' exposure to the air; and

[5] Jahres-Bericht. Wagner. 1861. p. 24.
[6] Tr. 2. p. 693.
[7] On the extraordinary effect produced on Cast-iron by the action of Sea-water. Engines of War. By Henry Wilkinson. London. 1841. P. 238.

there was no difference in the appearance of the substance before and after this combustion. "The inhabitants of Mull, and all who witnessed the phenomenon, were greatly astonished (as may naturally be supposed); and being themselves unable to solve the mystery, they applied to the surgeon of the ship, as being the most scientific man present; he was, however, as much at a loss to account for such unusual appearances as themselves, but said, that although they had been buried in the sea nearly 200 years, yet, as they went down in the heat of action, he supposed they had not had sufficient time to cool!"[8] In a naval engagement with the French off Portsmouth in 1545, the "Mary Rose," of the English fleet, was so overweighted with ordnance that she sank with all her crew of nearly 600 men. On the 16th of June, 1836, a 24-pounder "brass gun," 11 ft. in length, belonging to this vessel, was raised with the aid of a diving apparatus. This gun had a cast-iron shot in it, which, on exposure to the air, is stated to have become nearly red-hot and to have fallen to pieces. "At the same time," Mr. Wilkinson writes, "four brass and three iron guns were raised from the wreck of the 'Mary Rose.' The iron guns were of the ancient description, formed of iron bars hooped together with iron rings, and they were all loaded; but the guns being made of wrought or malleable iron, they did not exhibit the same phenomenon as the balls which were made of cast-iron. Those balls, which by their diameter ought to have weighed 30 lbs., were reduced to 19 lbs. 3 oz. The 8-inch or 70 lb. ones were only 45 lbs., although to external appearance the same as regular shot, until they fell to pieces *red-hot* on exposure to the air."

ALLOYS OF IRON.

Our knowledge of the alloys of iron is very imperfect. There are, it is true, numerous observations concerning the presence of various metals in steel and cast-iron, but there are few concerning alloys with comparatively pure iron. I shall present such information as I have been able to collect on this important subject under the three heads: Alloys with Pure Iron, with Steel, and with Cast-Iron; and, in order to make this volume as complete as possible in itself, I shall deviate from the plan which I announced in the first volume, namely, under each metal to treat only of its alloys with the metals previously considered. In the case of triple, etc. alloys, I shall adopt the following arrangement: the alloys of iron with the metals *a*, *b*, *c*, *d*, etc. being the order, the alloys of iron with *a*, *b* will be given under *b*, with *b*, *c* or *a*, *b*, *c* under *c*, and so forth.

Iron and Copper.

Rinmann heated strongly in a blast-furnace a crucible containing a mixture of 5 parts of iron and 1 of copper in the state of *copper-rain*.[9] The product was a well-melted convex button, of which the weight

[8] Wilkinson, p. 239.

[9] Vid. Metallurgy, First Part, 1. p. 410.

was somewhat less than that of the metals employed; it was hard and tough, and could only be broken with difficulty; its fracture was white with black points, presenting no signs of copper, but here and there upon the surface it had a copper-like skin.[1] With regard to the effect of copper on iron, the statements of Rinmann, as Karsten pointed out, are contradictory: thus, in one place he writes, "In ignorance it was believed that red-shortness in iron was specially due to copper, and some foreigners are so simple as to believe that Swedish iron generally contains copper, and is, therefore, red-short;"[2] whilst in another place he writes, "it cannot be denied that the presence of copper in bar-iron causes incurable red-shortness."[3]

Mushet made experiments on the "practicability of alloying iron and copper," and arrived at the following conclusions: "Pure malleable iron may be united with copper in any proportion, until it equals, or even exceeds, the weight of the copper; the intensity of the copper-colour increases till the quantities are equal; and the fracture then becomes paler, in proportion as the quantity of iron exceeds that of the copper. With 50 per cent. of iron the alloy possesses great strength: its hardness increases with the quantity of iron, but its strength afterwards decreases, and in cutting, it opens before the chisel."[4] The statement concerning the increase in the intensity of the colour does not agree with my experience, as will presently be shown.

According to Karsten, "Iron can only take up a certain, probably very small, percentage of copper, as copper can only combine with a small quantity of iron."[5] He also remarked that copper appeared to act very little upon the magnetic property of iron, as the presence of very small quantities of iron in copper may be detected by the magnet. The same authority, after alluding to the diversity of opinion concerning the effect of copper on iron, gives it as the general opinion of persons practically acquainted with the manufacture of iron, that copper renders iron red-short. In order to satisfy himself on this point he made experiments on the large scale. In the conversion of cast-iron into malleable iron in the charcoal hearth he added $\frac{1}{2}$ % of copper to the charge. During the whole process a lively green flame was emitted. The bar-iron produced was not in the least red-short. The experiment was repeated with the addition of 1 % of copper to the charge, when it was found that the iron of the lump would not weld properly, and after reheating three, four, or five times, it still remained unsound in places. On plunging a bar while heated to the highest temperature into water, a green flame proceeded from it; and by this means, Karsten states, the presence of copper becomes instantly manifest. Of eight bars obtained from this lump, six stood the usual proof, and the other two broke where cracks had appeared. Although the tenacity of the iron was not affected by the addition of 1 % of copper, yet its weldableness was sensibly diminished. Analysis showed that the bar-iron retained 0·286 % of copper. Karsten states

[1] Geschichte des Eisens. 1. p. 464.
[2] Op. cit. p. 462. [3] Ibid. p. 388.
[4] Phil. Mag. 6. p. 81. 1835.
[5] Eisenhüttenkunde, 1. p. 498.

that this cupriferous iron requires six times as long for solution in sulphuric or nitro-hydrochloric acid as pure bar-iron.

According to Professor Eggertz, of Fahlun, malleable iron containing 0·5 % of copper shows only traces of red-shortness.[6]

Longmaid has patented the addition of from ½ lb. to 2 lbs. of copper to the ton of iron.[7] The copper is put into the melted cast-iron in the refining or puddling processes. The patentee announces, what few will probably believe, that "the iron thus produced will be found to be possessed of a greater degree of hardness whilst retaining its ductility." I am not aware of any evidence in confirmation of the truth of this statement.

The following experiments on alloying iron and copper together have been made in my laboratory by Mr. Richardson. Thick iron-wire and electrotype copper cut in small pieces were employed, and fusion was effected under plate-glass in clay crucibles with luted covers.

1. Iron 200 grs. and copper 1000 grs. A well-melted button was produced, which weighed 8 grs. less than the metals used. It should have contained about 16·6 % of iron. It was copper-coloured externally, and flat on the upper surface with rounded edges; there was no excrescence, but near the circumference in one place was a slight depression, within which, under a lens, the metal consisted of a spongy agglomeration of minute confusedly crystalline particles. It was much harder and tougher than copper, and it was cut across with a cold chisel nearly through before the two pieces separated. It was scratched by fluorspar, but not by calcareous spar. The fracture was copper-red in colour, but somewhat paler than that of tough-pitch copper; in structure it appeared finely granular or bright and silky, according to the direction of the light incident upon it, and under a low power of a simple microscope it seemed homogeneous. However, Mr. Matthiessen informs me that he could not succeed in drawing out a piece of this metal into wire, in consequence, as he believes, of its want of homogeneity. Its toughness struck me as very great. It flattened out under the hammer at a dull redheat, but at the same time split. It is scarcely necessary to remark that observations as to the working qualities of a metal cannot be satisfactorily made with such a small piece as I operated upon.

2. Iron 300 grs. and copper 1000 grs. With the exception of 55 grs. of iron which remained unfused, the button was well melted. The loss was 22 grs. The fracture had a paler copper-red colour than that of No. 1; it was crystalline-granular; it appeared homogeneous, and I could not even by means of a lens detect any specks of iron upon it. The metal was not so tough as No. 1. It contained about 20 % of iron, deduction made of the unfused portion.

3. Iron 700 grs. and copper 700 grs. The loss was 80 grs. The button was well melted. It had a light pinkish copper-red colour, was very brittle, and fine-grained in fracture. It contained about 50 % of iron.

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[6] Jahres-Bericht. Wagner. 1862, p. 9.

[7] A.D. 1861. No. 1863.

4. Iron 700 grs. and copper 500 grs. The loss was 6 grs. The button was well melted. The central part of the upper surface was very slightly concave. This surface had the colour of iron, and appeared as though it were thinly plated with that metal; and under a lens it was seen everywhere to present crystalline markings like those of chloride of ammonium evaporated on glass. This plating of iron extended round the edges downwards, and irregularly over the lower surface of the button. The metal was very brittle. The fracture was similar in colour to that of No. 3; it was uneven and very distinctly crystalline; under a lens the metal was seen to consist of an agglomeration of crystals like those of chloride of ammonium above mentioned; there were indications of cleavage planes of considerable size, not smooth, but composed apparently of minute parallel facets, producing a sort of chatoyant lustre by varying the direction of the incident light. The metal contained about 58½ % of iron.

5. Iron 800 grs. and copper 200 grs. The loss was only 2 grs. The button was well melted. The metal was extremely brittle. The fracture had a pale coppery-grey colour, the tint of which varied with the direction of the incident light; it was crystalline granular, and presented the peculiar chatoyant effect in a much higher degree than No. 4. Copper-red particles appeared here and there, and especially at the bottom of the button. Under a low power of a simple microscope the fracture was an interesting object; it was composed of iron-grey mica-like scales intermingled with red copper-like particles. The metal contained 80 % of iron.

The metal in each of the preceding experiments acted strongly on the magnetic needle.

Mushet obtained the following results on fusing copper with steel and cast iron.[8] Steel melted with 5 % of its weight of copper was considerably hardened, useless for forge-purposes, and incapable of taking an edge. The ingot was crystallized like cast-steel, and showed no trace of copper either on the external or fractured surfaces. Copper melted with 10 % of its weight of bar-steel gave an ingot outwardly similar in appearance to the last, but with the "radiated linear crystallization less distinct," was hard and brittle, and minute points of copper were visible on the fracture. [It is so printed, but surely the copper and iron should be transposed.] An ingot obtained by melting steel with 20 % of its weight of copper: when filed it appeared coppery red on the lower and steel-bright on the upper surface; the fracture was regular in grain. Steel melted with ¼ of its weight of copper gave an ingot, consisting of copper at the bottom; copper appeared in streaks and knots on the fractured surface. White cast-iron afforded nearly the same results when melted with similar proportions of copper; but there was a greater tendency to separation when the copper exceeded 5 %. When No. 1 grey-pig iron was melted with 5 % of copper, specks of red copper were found upon the lower surface of the ingot and on the fractured surface; with

[8] Phil. Mag. ante cit.

10 % the copper attached itself in leaves to the outside of the cast-iron; and with 20 % a solid button of copper was found underneath the cast-iron at the bottom of the crucible. Mushet concluded that "copper unites with iron in proportion as the latter is free from carbon."

Faraday and Stodart melted steel with 2 % of copper, but the quality of the metal did not appear to be at all improved.[9]

Stengel has published a paper concerning the influence of sulphur, silicon, and copper on the quality of iron and steel;[1] but as only the proportions of these elements were determined, conclusions drawn from his results must be cautiously received. These results, however, are sufficiently important to be presented *in extenso*, especially as great attention has of late been given by really intelligent British iron-masters to the analysis of the various kinds of iron in commerce with a view to determine the causes of this remarkable difference in quality.

TABLE OF STENGEL'S RESULTS.

The sign — indicates that the element was sought for, but not found; and the sign ... that it was not sought for.

IRON.

No.	S per cent.	Si per cent.	Cu per cent.	Locality.
1	0·002	0·056	—	District of Saarbrück.
2	0·004	0·048	0·07	From the Eifel.
3	0·013	0·050	—	English puddled iron.
4	0·016	0·076	—	Halberg Forge, Saarbrück.
5	0·116	0·192	—	Sent from Bonn; where made unknown.
6	0·018	0·038	0·21	Puddled iron, from the Alf, near Kochem.
7	0·015	0·096	0·44	Siegen.
8	0·032	0·278	0·38	The Harz.

[9] The Quarterly Journal of Science, Literature, and the Arts, 9. p. 329. 1820. Philos. Trans. 1822, p. 266.

[1] Über den Einfluss des Kupfers und Schwefels auf die Güte des Stahls. Karsten's Archiv, 10. p. 744. 1837. The title of Stengel's paper should be what I have stated in the text.

NOTE.—I shall have frequent occasion in the sequel to refer to the experiments of Faraday and Stodart on the alloys of steel, and it may be well here to state the mode in which they were conducted. "In making the alloys on the large scale," they write, "we were under the necessity of removing our operations from London to a steel furnace at Sheffield; and being prevented by other avocations from giving personal attendance, the superintendence of the work was consequently intrusted to an intelligent and confidential agent. To him the steel, together with the alloying metals in the exact proportion, and in the most favourable state for the purpose, was forwarded, with instructions to see the whole of the metals, and nothing else, packed into the crucible, and placed in the furnace, to attend to it while there, and to suffer it to remain for some considerable time in a state of thin fusion, previous to its being poured out into the mould. The cast ingot was next, under the same superintendence, taken to the tilting mill, where it was forged into bars of a convenient size, at a temperature not higher than just to render the metal sufficiently malleable under the tilt hammer. When returned to us, it was subjected to examination both mechanical and chemical, as well as compared with the similar products of the laboratory. From the external appearance, as well as from the texture of the part when broken by the blow of the hammer, we were able to form a tolerably correct judgment as to its general merits; the hardness, toughness, and other properties, were farther proved by severe trials, after being fashioned into some instrument or tool, and properly hardened and tempered."[2]

[2] Phil. Trans. ante cit. p. 254.

STEEL.

No.	S per cent.	Si per cent.	Cu per cent.	Locality.
9	0·002	0·115	—	Crude steel, from near Eisenerz, Styria.
10	0·028	...	0·02	Brescian steel.
11	0·002	0·062	0·39	Oberhunden, near Lohe.
12	0·008	0·163	0·27	From Lohe, Siegen, made wholly from Stahlberg spathic ore.
13	0·011	0·144	0 40	Ordinary steel from Lohe.
14	0·006	0·077	0·36	Steel made from Salchendorf highly manganesiferous brown iron ore.

Observations.—In Nos. 1, 2, and 3 the iron presented no trace of red-shortness. In No. 4 there was only a slight tendency to red-shortness. No. 5 was in the highest degree red-short. No. 6 showed some tendency to red-shortness, whereas No. 3 was perfectly free from this defect, and scarcely differed in composition from No. 6, except as to the absence of copper. In No. 7 there was a trace of red-shortness; and Stengel gives 0·44% of copper as the limit at which red-shortness, due to the presence of this metal, may be said to commence. It was only when drawn out into thin pieces that it showed its inferiority to iron free from copper. No. 8 was red-short, but still might be bent without breaking. That red-shortness in this instance was not due to copper, is proved by reference to No. 7. The tenacity of iron is not affected by the presence even of more than ½% of copper, at least not when the metal is drawn out to the thinness of hoops, although it may be rough at the edges.

With regard to steel, Stengel observes that No. 10, or Brescian steel, surpasses all the other kinds of steel in the table, except No. 9; and draws attention to the fact that this superiority is connected either with the total absence of copper, or with its presence only in minute proportion; or, conversely, that all the inferior kinds of steel in the table contain a comparatively large proportion of copper. Hence he refers this inferiority to copper. It cannot be due to sulphur, because Brescian steel contains more than any of the other varieties in the table. The presence of copper in sensible quantity in either iron or steel is indicated by the rough and black appearance of the surface of the metal after heating to redness and quenching in water. No. 9 is well adapted for scythes. The chief results at which Stengel arrives from his researches are as follow:—1. All sorts of iron and steel free from copper, when scaled by heating to redness and quenching in water, give a silver-white surface at the edges, whereas with from 0·27% to 0·4% of copper, the surface thus scaled is black and rough; thus, No. 5, which was very red-short from the presence of sulphur and silicon, and which contained no copper, when scaled after heating to yellow-redness, left a silver-white surface at the edges, though full of cracks. 2. The presence of 0·116% of sulphur and 0·192% of silicon, *without copper*, renders iron and steel red-short and useless. 3. The presence of 0·015% of sulphur and 0·44% of copper causes incipient red-shortness. 4. A considerably less proportion of

sulphur is required to induce decided red-shortness in iron than of copper. The addition of 0·1 % of sulphur is, perhaps, more injurious to the strength of iron than that of ¾ % of copper and upwards.

According to Eggertz, steel made from iron containing only 0·5 % of copper is good for nothing.[3]

I have previously described[4] the cupriferous cast-iron produced in copper-smelting in Perm. It was white, containing 12·64 % of copper and 3·03 % of carbon. Particles of metallic copper were disseminated on the fractured surface, and no statement is given as to the amount which may have been alloyed, or at least intimately mixed, with the metal. By melting the cupriferous cast-iron in a hearth, and protecting the surface from oxidation, copper containing about 20 % of iron accumulates at the lower part, and may be tapped off from the superjacent stratum of cast-iron, which retains from ½ % to 2 % of copper, and which, according to Krilowski, is well adapted for casting. It runs into the smallest cavities, and scarcely contracts on solidification; it is susceptible of a fine polish, and hardens like steel; its fracture after rapid cooling is bright and lamellar, and after slow cooling dull and finely granular; it may be turned in the lathe with the greatest facility, and it is even somewhat malleable. Castings of this metal on leaving the mould are covered with a continuous though extremely thin layer of metallic copper, so that after exposure to the air during some time they acquire exactly the tint of bronze.[5] Attempts were previously made at Liége to alloy cast-iron with copper, but they resulted in failure, and no true alloy could be obtained.[6]

Iron and Zinc.

Old chemical authors record the results of numerous and varied experiments to alloy these metals directly together, and it was generally concluded that they did not alloy. However, Bosc-d'Antic found that zinc melted in contact with iron in close crucibles acquired a somewhat steel-grey colour, was not rendered malleable, did not rust, preserved its lustre, melted on charcoal before the blowpipe, was very readily attracted by the magnet, and gave to hydrochloric acid the same colour as iron, forming a solution which produced ink with infusion of nut-galls, and Prussian blue with ferrocyanide of potassium.[7] Hence there can be no doubt that he obtained an alloy of zinc and iron. Although molten zinc speedily takes up a little iron, whether cast or wrought iron, yet it is only by long contact of the two metals under this condition that they can be properly alloyed. This occurs in the process of zincing iron, in which a large quantity of zinc is kept melted in iron vessels. The iron is slowly corroded and an alloy is produced, which, having a higher melting-point and a

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[3] Jahres-Bericht. Wagner. 1862. P. 9.

[4] Metallurgy, First Part, p. 434.

[5] Notice sur la fonte alliée de cuivre. Ann. des Mines, 3 ss. 16, p. 197. 1839. Quoted from the Ann. des Mines Russes. 1836. No. 1.

[6] Ann. des Mines, 3 ss. 3. p. 233. 1833.

[7] Geschichte des Zinks. Fuchs. 1788. p. 296.

higher specific gravity than zinc, accumulates on the bottom. It is detached at intervals, and at one establishment I have seen more than 60 tons of it in large lumps at one time.

Hollunder seems to have first ascertained the conditions under which the alloy of iron and zinc is formed, and to have recognised the true nature of the incrustation produced in iron vessels in which zinc is melted. He made numerous and ineffectual attempts to alloy the two metals rapidly together, and he tried to unite them by the intervention of tin and arsenic. He published two papers in which he recorded his experiments, and gave a complete account of all previous researches on the subject. These papers are tediously minute, and will now hardly repay perusal.[8]

Berthier states that "iron and zinc combine in *all* proportions when heated slowly together without contact of the air;"[9] but this is surely erroneous. At a high temperature the zinc is wholly volatilised, and hence, as Berthier correctly remarks, the cast-iron obtained in smelting zinciferous ores of iron is free from zinc. I have in vain sought for zinc in pig-iron from one of the Stanhope furnaces in the North of England, where zinc vapour was burning at the top with a highly luminous flame and with the deposition of a crust of oxide round the mouth. Karsten found zinc in the pig-iron yielded by calaminiferous iron ores expressly used, but the proportion was too small to be estimated.[1]

Berthier has given the following analyses of alloys detached from the bottom of cast-iron vessels in which zinc was melted preparatory to lading. He describes them as mammillated and largely crystalline in grain.

	1.	2.
Iron per cent.	4·7	4·0
Graphite do.	0·3	0·2

No. 1 was from Liége, and No. 2 from Gisors.

Herapath obtained a metallic incrustation from the interior of the iron tube leading from a retort in an English zinc furnace.[2] It was composed of 92·6 % of zinc and 7·4 % of iron. Its specific gravity was 7·172; it was extremely hard and brittle; its fracture showed broad facets like zinc, but it had a duller grey colour, and its surfaces were more rough and granular than zinc.[3]

Many years ago I obtained from the Gospel Oak Works, near Birmingham, where the process of galvanising iron was conducted, a specimen of the alloy which, on the exterior, consisted of confusedly interlaced short crystalline prisms. The fracture presented large facets studded with minute grey specks which render it dull in lustre as compared with the fracture of ordinary zinc. The metal is hard and brittle, and, as was remarked by Hollunder, dissolves very rapidly in hydrochloric or dilute sulphuric acid, so that it may be conveni-

[8] Journal für Chemie und Physik. Schweigger u. Meinecke. 23. pp. 41-61 and 166-195. Nürnberg, 1821.

[9] Tr. 2. p. 575.

[1] Eisenhüttenk. 1. p. 519.

[2] Vide Metallurgy, First Part.

[3] Phil. Mag 61. p. 167. 1823.

ently employed for making hydrogen. It contained 3·00 % of iron and a little lead. I received a specimen of the alloy from the late Mr. T. H. Henry, consisting of a confused aggregation of imperfectly formed crystals, which appear to be more or less prismatic: it contains 9·4 % of iron. The composition of this alloy may be nearly represented by the formula $Zn^{12}Fe$. It is probable that iron and zinc may unite in variable proportions and yet produce alloys of the same crystalline form, as Professor Cooke, of Harvard College, U. S., has shown to be the case with alloys of zinc and antimony; and Mr. Storer, of the same College, with alloys of copper and zinc.[4] Erdmann analysed acicular crystals detached from a piece of distilled zinc left in water upon chloride of silver, which the zinc had reduced. They consisted of 93·193 % of zinc, 6·524 % of iron, and 0·283 % of lead. Their composition, therefore, nearly corresponds to the formula $Zn^{12}Fe$, and they evidently closely resemble the crystals above described, which, from their mode of formation, might be expected to contain zinc, mechanically intermixed.[5] Mr. Abel, of the Arsenal, has communicated to me some observations which he has made on crystallized alloys of zinc and iron accidentally produced. A mass composed of aggregations of small prisms was found by him to have the following composition:—

Zinc	91·80
Iron	7·45
Lead	0·75
	100·00

There was no sulphur. This approximates closely to the formula $Zn^{10}Fe$, which requires 7·90 % of iron. Other specimens contained 8·2 % and 7 % of iron respectively. A mass having a dense crystalline fracture, not unlike that of white pig-iron, contained 10·8 % of iron. Laurent and Holms have described crystals of zinc which were formed in an earthenware pipe used as a receiver in the extraction of the metal. They were prisms with a rhombic base, and contained from 3 % to 4 % of iron.[6]

The process of zincing, or, as it is termed, galvanizing iron is very extensively practised in order to prevent rusting. The articles, after having been thoroughly freed from scale by "pickling," etc., are immersed in a bath of molten zinc covered with sal-ammoniac, whereby they acquire a firmly adherent superficial coating of this metal. The history of this invention is interesting. It is stated that Malouin so long ago as 1742 ascertained that a sort of tin-plate might be made with zinc.[7] The following passage occurs in Bishop Watson's widely circulated Chemical Essays, published in 1786.[8] "A method has of late years been introduced at *Rouen* of applying a coat of zinc

[4] Memoirs of the American Academy. New Series, 8. 1860.

[5] Berzelius, Tr. 2. p. 620.

[6] Ann. de Chim. et de Phys. 60. p. 333. 1835.

[7] Dumas, Tr. de Chim. appliquée aux Arts, 3. p. 218. 1831.

[8] 4. p. 177. Quoted from Journ. de Phys. Decem. 1778.

upon *hammered* saucepans. The vessels are first made very bright, so that not a black speck can be seen; they are then rubbed with a solution of sal-ammoniac and afterwards dipped into an iron pot full of melted zinc, and, being taken out, the zinc is found to cover the surface of the iron; and if a thicker coat of zinc is wanted, it may be obtained by dipping the vessel a second time. This kind of covering is so hard that the vessels may be scoured with sand without its being rubbed off." Yet a patent was granted for this process in 1837,[9] and another in 1841,[1] the only difference being that in the last the surface was first coated with tin or its alloys in the ordinary manner. Litigation, as was to be expected, occurred, and the chief gainers were, as usual, the lawyers. It deserves to be noted that Dumas in 1831 expressed the opinion that there was "little probability that this variety of tin-plate should have useful applications." But he adds it may be "possible that, by substituting an alloy of zinc and tin for pure zinc, one might arrive at good results."[2] The prediction has proved singularly infelicitous.

Iron, Copper, and Zinc.[3]

In 1779 a patent, which now deserves particular attention, was granted to William Keir: its title is for "A compound metal capable of being forged when red hot or when cold, more fit for the making of bolts, nails, and sheathing for ships than any metals heretofore used or applied for those purposes, and also for various other purposes where other metals have been used or applied."[4] This alloy is made by combining together "100 parts by weight of copper, 75 parts of zinc or spelter, and 10 parts of iron." It is directed that the iron and copper should be first melted together in the presence of charcoal, and pounded glass or other fluxes, and that then the zinc should be added by degrees. Supposing no loss to occur, the alloy would consist of 54·05 % of copper, 40·54 % of zinc, and 5·40 % of iron, *i.e.* it may be regarded as Muntz's metal in which about 5 % of the copper is replaced by the same weight of iron.

A patent for an alloy nearly identical with that of Keir was granted in 1860, founded on a communication by Johann Aich, officer in the Imperial Marine, Venice.[5] The alloy is commonly known, at least in Germany, as *Aich metal.* If properly made, it may be worked both in a hot and cold state. At a red heat it is described as being malleable like the best wrought iron, and may be hammered, rolled, stamped, drawn into wire, wrought into any shape, or cast

[9] To Henry William Craufurd. A.D. 1837, April 29. No. 7355.

[1] To Edmund Morewood. A.D. 1841, Aug. 27. No. 9055.

[2] Op. cit.

[3] It will, probably, be thought that the following description is out of place in this volume, and I admit, with some reason. But if the importance of a metallic constituent of an alloy is to be judged by its effect, and not by its quantity, then the alloy in question may be here considered, as it owes its peculiar properties to the presence of a small proportion of iron.

[4] A.D. 1779, December 10. No. 1240.

[5] A.D. 1860, Feb. 3. No. 278. "Improvements in Amalgamating Metals or producing Alloys."

into moulds. Experience has demonstrated that the best proportions in 100 lbs. of the alloy are 60 lbs. of copper, 38 lbs. 2 ozs. of zinc, and 1 lb. 8 ozs. of iron. While the proportion of copper is constant, the zinc may be increased to 44 %, and the iron reduced to 0·5 % or raised to 3 %. This alloy is recommended on account of its cheapness as a substitute for copper and brass in shipbuilding and sheathing; it is much stronger than copper, and is said to resist the action of sea water satisfactorily. The Aich metal, it will be perceived, contains at its maximum about 2 % less of iron than Keir's alloy; but the proportions which Keir gives are those to be employed in making his alloy, whereas those given by Aich should exist in the alloy when made. Aich particularly states that "an overplus of one or other of the metals (and especially zinc) must be added, as, through oxidation and sublimation, certain portions thereof will inevitably be lost during the process of fusion." I should be surprised if, even according to the present patent law, Aich could establish his patent in the face of the old patent of Keir.

Very similar alloys to this have been introduced by Baron Rosthorn at Vienna under the name of *sterro-metal*, from the Greek word signifying "firm," which are stated to possess very valuable qualities, and which closely approximate in composition to that so long ago patented by Keir. They differ, however, from the latter in containing less iron and a small proportion of tin. The Baron has supplied me with copious information respecting his alloys, which he recommends for ordnance and all purposes where great resistance to friction is needed. They are composed of 60 parts by weight of copper, from 34 to 44 of zinc, from 2 to 4 of iron, and from 1 to 2 of tin. The directions for making them are as follow:—The iron, which must be malleable iron, is put at the bottom of a crucible with the copper upon it, and then exposed to a *very high* temperature. It is thus completely taken up by the copper, and when the whole is fused the tin is added and afterwards the zinc. The melted metal is to be stirred, left for a minute or two, stirred again, and cast. Two qualities of alloy are made, one designated soft and the other hard; the former is more ductile when cold, and fitter for being worked into sheets and wire, and the latter is suitable for ordnance.

Baron de Rosthorn has presented me with a series of the identical specimens of the harder alloys, of which the tensile strength has been actually determined. They are brass-yellow in colour; their fracture is fine and close in grain, and free from all appearance of porosity; and they are susceptible of a fine polish. It is stated that they are now exclusively used by Vienna engineers for the pumps of hydraulic presses. Their tensile strength under different conditions of treatment has been accurately determined at the Polytechnic Institution at Vienna; and the official record of these results is now presented in a tabular form precisely as I received it. The results of comparative trials with gun-metal or bronze are also given in this statement.

Record of the **Experiments** on the Tensile Strength of bars of Sterro-metal as Gun-metal in the Polytechnic Institution, Vienna, in the presence of Commodore Baron Wüllerstorf; Artillery Col. de Paradis; Mr. Braun, Director of Mr. Dingler's Machine Factory; Mr. Christian Starke, the Superintendent; and Mr. Gustavus Starke, the Assistant of the workshops of the Institution. Dated October 12, 1861.

Number of experiment.	Sort of metal.		Its state.	Area of section in Aust. sq. inches.	Weight required to rend the bar. (In Austrian cwts.)	Absolute strength of an Aust. sq. inch. (In Austrian cwts.)	Average absol. strength per sq. inch. (In Austrian cwts.)	Remarks.
1	Sterro-metal.	harder sort	cast	0·096	46,5	482	...	Through an error of production found not homogeneous.
2			cast	·096	56,5	591	524	Equal to 27 tons (English) on the sq. inch (English).
3			cast	·100	50,0	500		
4			forged	·112	72,0	643		
5			forged	·117	80,1	685	669	= to 34 tons (English) on the sq. inch (English).
6			forged	·100	68,0	680		
7			once drawn cold	·097	72,0	742		
8			once drawn cold	·077	56,7	738	740	= 38 tons (English) on the sq. inch (English).
9			once drawn cold	·097	...	...	...	Laid aside untested, owing to its having been found faulty.
10		softer sort	cast	·096	42,5	443		
11			cast	·102	48,0	470	459	
12			cast	·115	53,5	465		
13			forged	·123	66,5	540		
14			forged	·105	59,5	567	549	
15			forged	·124	67,0	540		
16			once drawn cold.	·098	61,0	622		
17			once drawn cold.	·103	69,0	670	645	
18			once drawn cold.	·100	64,2	642		
19			twice drawn cold.	·074	53,5	728		
20			twice drawn cold.	·074	53,8	732	729	
21			twice drawn cold.	·067	49,0	727		
22			thrice drawn cold.	·064	49,0	767		
23			thrice drawn cold.	·070	52,0	743	750	
24			thrice drawn cold.	·045	33,3	741		
25	Gun metal, composed of 89·9% of copper, 10·1% of tin.		cast	·129	44,0	341		
26			cast	·124	49,7	385		
27			cast	·123	42,5	345	358	= 18 tons (English) on the sq. inch (English).
28			cast	·106	44,7	422		
29			cast	·118	42,6	361		
30			cast	·121	35,5	293		

Observations.—The bars subjected to trial were not quadrangular, but cylindrical, having been turned in the lathe, and their respective diameters were determined by the aid of a microscopic apparatus.

In order to obtain accurate comparative results for both sterro-metal and bronze, the same sorts of materials, viz. Baltimore copper and good English tin, were used.

The tensile strength of a hard variety of these alloys has also been ascertained at the Imperial Arsenal at Vienna. The sample operated on was prepared under identically the same conditions and with the same qualities of component metals as another tested at the Polytechnic Institution. The results confirm the accuracy of those obtained at the last establishment, and are as follow:

Tensile strength after simple fusion, 28 English tons to the English square inch of sectional area; after forging at a red heat, 32 tons; drawn cold and reduced from 100 to 77 of sectional area, 37 tons.

Analyses of the alloy thus tested were made in the laboratories of the Polytechnic Institution and Imperial Mint respectively, and the results are as under:

	1.	2.
Copper	55·04	57·63
Zinc	42·36	40·22
Iron	1·77	1·86
Tin	0·83	0·15
	100·00	99·86

Experience has proved that the proportion of zinc may vary from 38 to 42 per cent. without materially affecting the quality of the alloy. The specific gravity of the forged metal was 8·37, and that of the same metal drawn cold into wire 8·40. The hardness of the cast metal somewhat exceeds that of ordinary gun-metal, and is augmented by forging. The great tensile strength of the sterro-metal is remarkable. But this alloy possesses another quality, which, in reference to its application for guns, is regarded as more important even than its high tenacity, namely, great elasticity. It is not permanently elongated until stretched beyond $\frac{1}{600}$ of its length; and within that limit it is perfectly elastic, recovering its original form after the stretching force is withdrawn. Field guns, from 4 to 12-pounders, have been worked out of single pieces under the hydraulic press, whereby expensive forging is avoided; and reliable experiments have demonstrated that after this treatment the metal has precisely the same properties and the same tensile strength as bars of it drawn out under the steam-hammer.[6]

Sterro-metal was accidentally discovered in attempting to apply the ferriferous alloy of zinc, obtained in the process of "galvanizing iron," to the preparation of brass. It has been made the subject of careful experiment at the Arsenal at Woolwich, and the results there obtained confirm the correctness of the preceding statements.

An alloy, consisting of 80% of zinc, 10% of copper, and 10% of iron, has been proposed by M. Sorel under the name of *unoxidizable cast-iron* or *white brass*.[7] It is reported to have the fracture and appearance of common zinc, to equal copper and iron in hardness, to be more tenacious than soft cast-iron, to be susceptible of turning, filing, and

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[6] An account of these results appeared in *The Times*, Dec. 12, 1862, and Feb. 3, 1863.

[7] Ann. des Mines, 3. s. 17. p. 647. 1840.

tapping as well as these metals, not to adhere to metallic moulds in which it is cast, and to keep in moist air without rusting at all or losing its metallic lustre in the least degree. It may be very easily bronzed, whether by metallic precipitation, or by setting free the copper which it contains; and it is, therefore, recommended as well adapted for statues, or other ornamental objects which are to be exposed to the atmosphere. It is prepared by melting together with suitable precautions zinc, copper, and cast-iron. According to the composition stated above it contains iron, and not cast-iron. This point is not very clear.

Iron and Manganese.

We have already considered carburized alloys of iron and manganese, but the presence of carbon, it need hardly be remarked, may be expected to modify the properties of any alloy in a material degree. With regard to alloys of pure iron and pure manganese, I do not know whether anything satisfactory has been published: I have met with nothing of the kind.

Iron and Tin.

The affinity of iron for tin is well exemplified in common tin-plate, which is nothing more than sheet-iron firmly coated with tin by simple immersion under suitable conditions in a bath of molten tin. The tin thus strongly adheres to the surface of the iron. An alloy of iron and tin, or of iron, tin, and arsenic, is produced in the usual process of tin-smelting. Berthier has specially described the two following alloys. One contains 35·1 % of tin, which agrees with the formula Fe^4Sn; it is iron grey, crystalline, and so brittle as to admit of being reduced to impalpable powder. The other contains 50 % of tin, melts at 50° (Wedgwood's pyrometer), is greyish white, very brittle, and granular in fracture. The first of these alloys has been examined in my laboratory: it was made by melting together at a white heat 1120 grs. of thin sheet-iron, and 590 of tin. The alloy was hard and brittle, and its fracture was light-grey in colour, crystalline, presenting small planes set at varying angles; each plane was finely granular, producing dulness of lustre, just as is the case with zinc containing much iron. It was magnetic. Hydrochloric acid, without the aid of heat, acted feebly upon it; and nitric acid acted vigorously at first, but soon ceased. Deville and Caron have described an alloy of the formula FeSn; it crystallized out from solution in excess of tin in broad laminæ, and was only feebly attacked by hydrochloric acid.[a] Nöllner has described an alloy of the formula $FeSn^2$, crystallized in small four-sided prisms. In dissolving East Indian tin in hydrochloric acid, there was an insoluble residue, and in this the crystals were found. The alloy had a specific gravity of 7·446; it was nearly insoluble in nitric and

[a] Jahres-Bericht, u. 1858, p. 190.

hydrochloric acids, but readily soluble in nitro-hydrochloric acid; when thrown into the flame of a candle, it burned with scintillation and white smoke; it fused at a white heat, and the solidified crystalline mass was magnetic, though it is stated the original crystals were not.[9] Tin and iron may be melted together in all proportions, forming apparently homogeneous alloys; but when an alloy containing sensibly more than the third of its weight of tin is heated gently at or slightly above the melting-point of tin, liquation of tin occurs until the more or less definite alloy Fe^4Sn is left. The liquated tin, however, carries away some iron.

Karsten observed the effect of adding 1 % of the purest English tin to a charge of cast-iron during the process of conversion into malleable iron in the charcoal hearth. The iron obtained was not exactly red-short, as it worked very well under the hammer; but, at a white-heat, white vapours escaped, which condensed as a white deposit upon the hammer and anvil. At a strong heat the iron readily fell to pieces under the hammer, so that in order to become sound several welding-heats were necessary; it had thus lost greatly in weldability, and was in a high degree cold-short. Not a single bar stood the usual test, but all broke immediately into several pieces when struck across the anvil. This iron, which was utterly worthless, was found by analysis to yield only 0·19 % of tin.[1]

Mr. Levick, of the Blaina Iron-works, has communicated to me the following results of experiments on attempts to harden the tops of rails with tin, according to Stirling's patent.

"From 2½ lbs. to 3 lbs. of block tin were added to each puddler's charge of 4¾ cwts. of pig-iron. The tin was put in immediately the iron was all melted. It did not seem to affect the process of puddling; but immediately it was charged it produced a very large quantity of white smoke, which escaped in large volumes from the top of the stack until the puddling was completed. The iron would not stand the same amount of heat in balling up as without the tin. When shingled under the squeezer it fell to pieces very much, and was difficult to roll. In rolling at the puddle-bar rolls, as also in the mill, the workmen's tongs became covered with a white deposit, caused by a white smoke emitted from the iron during rolling: this deposit would easily wipe off, or be washed off when the tongs were dipped in the water bosh. On piling and reheating the puddle-bars for making the slab for the tops of the rails, the iron would not stand so much heat as without the tin, and would crumble if raised to the ordinary heat and crack in rolling. When the tin hardened slab was worked in the rail pile, great care was required to get it to weld; the top would not take the heat required for the iron in the rest of the pile. The puddle-bar was very brittle and crystalline, but the slab rather less so; and by the time the rail was finished a considerable portion of the tin had worked out, and it was with difficulty the purely crystalline top could be maintained."

[9] Jahres-Bericht, L. u. K., 1860, p. 188. [1] 1. p. 508.

Longmaid has patented the addition of tin in small quantity to cast-iron during the processes of refining or puddling.[2] From 1 to 2 lbs. to the ton of iron is preferred, and in no case should the amount exceed 4 lbs.; for, then, the iron would be rendered hard and brittle. The patentee declares that "by using the minute quantity above mentioned, increased hardness and strength is obtained to the iron without improving [impairing ?] its tenacity" (*sic*). The language of our modern specifications is frequently disgraceful to the scribe; and of this the sentence just quoted is an example.

Faraday and Stodart in their paper on the alloys of steel simply observe that "steel also alloys with tin," and they express their doubts of the value of this alloy.[3]

Rinmann made numerous experiments on alloying cast-iron and tin together. With $\frac{1}{11}$ of tin the molten metal flowed as thin as water; it was very brittle and hard, light-grey in fracture, and as dense as the finest cast-steel; it was attracted by the magnet like pure iron. Rinmann calls attention to the fact that this alloy did not rust, although left for more than a year in a damp place. On this account he considered it suitable for ornaments and mirrors, especially as it melted more easily than cast-iron, ran thin, and took an exact impression of the mould, had a whiter colour than cast-iron, was extremely compact in structure, took a beautiful polish, and did not in the least degree discolour the hands or linen by friction. It gave as good a tone as bell-metal; he actually cast a bell in sand from cast-iron, to which a little tin had been added; and although the experiment was not perfectly successful, he was satisfied of improving the tone of iron by admixture with tin. In the Great International Exhibition of 1851 was a large bell of cast-iron stated to be alloyed with a small proportion of tin.

Mr. Denison has favoured me with the following remarks concerning this bell:—"The bell of 'Stirling's Union Metal' in the Exhibition of 1851 was of nearly hemispherical form, about 4½ ft. in diameter, and much thinner than bells of the usual shape and equal diameter, or even smaller ones of equal weight. Its sound was inferior in quality to bell metal either in the same form or in the usual form of bells; and it required a very much stronger blow to bring out the sound. It was at last broken by ringing it with a sledge hammer."

It was exhibited by the late Morries Stirling, who had included this alloy in a patent.[4] A small hand-bell of the same alloy is in the metallurgical collection in the Museum of Practical Geology. I have cast a small bell with white cast-iron melted with 5 % of tin; the tone seems pretty good, but is more shrill, and very much inferior in quality of sound to a bell of the same dimensions composed of copper alloyed with 24 % of tin. With 20 % of tin, the alloy was similar to the last, but whiter and somewhat harder. The quality of the cast-iron is not stated, though it was, probably, white, as in other

[2] A.D. 1861, No. 1863.
[3] Quarterly Journ. ante cit. p. 329.
[4] A.D. 1848, No. 12,288.

experiments grey cast-iron is specially mentioned. Equal weights of grey cast-iron and tin melted together did not properly unite; for the former lay as a button on the latter, from which it could be detached by the hammer. A similar result was obtained by melting cast-iron with twice its weight of tin. A mixture of 3 parts by weight of cast-iron and 10 of tin gave a button which seemed pretty homogeneous; it was semi-malleable, and in fracture resembled somewhat coarse cast-steel; small shots of iron were disseminated through the mass. Cast-iron melted with 10 times its weight of tin gave an apparently uniform alloy, which could be beaten out into thin sheet; but it still contained numerous shots of cast-iron. In experiments at Liége it was found that the addition of from 2 % to 5 % of tin to cast-iron produced a homogeneous, very hard, fragile metal, of little tenacity.[5]

Eyferth has experimented on the action of tin on cast iron.[6] According to this observer, if 25 of % tin is added to, and stirred with, molten grey cast-iron, the whole of the *dissolved*, i.e. uncombined or graphitic, carbon rises to the surface in the state of very light and bulky graphite. An alloy is thus formed which is very liquid and tenacious, though brittle, and resembling in fracture alloys of lead with antimony and arsenic. After pouring out the alloy, an astonishing amount of graphite will remain in the vessel, and at the bottom there will be found another more stanniferous alloy, mostly covered on the surface with an adherent layer of very fine graphite powder: this alloy is softer than the preceding, yet quite as brittle, but brighter in fracture. When the operation is performed in a crucible, and this, after the introduction of the tin and repeated stirring, is kept hot for some time, both alloys unite with the separation of silicon into one extremely liquid alloy, which after pouring out often ejects flocks of silica, and in fracture resembles the most compact cast-steel. It appears that the tin displaces only the uncombined or graphitic carbon, and that the whole of the combined carbon is retained in the stanniferous alloy. By the addition of about 10 % of tin, the uncombined carbon is only partially expelled; and the alloy, which is very liquid, can hardly be distinguished in fracture from bright-grey cast-iron; it may be filed, and is susceptible of hardening like ordinary steel. However, by very slow cooling, white-iron containing clusters of graphite scales is produced. When tin is added to molten white cast-iron, not a trace of carbon separates; but Eyferth has made only a few experiments on this point.

IRON AND TITANIUM.

It is only recently that we have had accurate information concerning metallic titanium, and for this we are indebted to the trustworthy and indefatigable Wöhler.[7] Prepared by reducing the fluo-titanate of potash by potassium, it is an amorphous grey powder, resembling iron

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[5] Ann. des Mines, 3 sér. 3. p. 233. 1833.
[6] Jahres-Bericht, Wagner, 1861, p. 22.
[7] Ann. de Chim. et de Phys. 3. s. 29. p. 181. 1850.

reduced by hydrogen at a low temperature. Magnified 200 times, it appears in fritted masses, having the colour of iron and a metallic lustre. Heated in the air, it burns with lively scintillation. The smallest particle of the metal projected into a flame produces a brilliant starlike spark. Heated in oxygen it occasions an instantaneous dazzling flame like lightning, titanic acid (TiO^2) being the result. Wöhler expresses his belief that there is no other body which burns so energetically in oxygen-gas. It decomposes water at 100° C. feebly. Wöhler disbelieves in the so-called brass-yellow or copper-coloured titanium described by Berthier, Laugier, and others, and obtained by reducing titanic acid in brasqued crucibles in a smith's fire, except it should be established that there are two different allotropic states of this metal. At high temperatures it combines not only with oxygen, but also with nitrogen, and, even in this gas, remarkable to say, combination is attended with the evolution of heat and light.[8] Wöhler has described three nitrides of the formulæ TiN, Ti^5N^3, Ti^3N^2. There is also a fourth, of the formula Ti^3N, which has not been isolated, and which is supposed to exist in the compound occurring in blast furnaces, to be presently mentioned. The nitrides of the formulæ Ti^5N^3 and Ti^3N^2 may, according to Wöhler, be represented by the formulæ $2TiN + Ti^3N$ and $3TiN + Ti^3N$, respectively.

Titanium, as will be hereafter shown, is frequently present in small quantity in the iron ores smelted in this country; and a remarkable compound of titanium in copper-coloured cubical crystals occurs in the ferruginous mass or "bear," which accumulates on the bottom of the hearth of the blast-furnaces. Wöhler first ascertained that it is a cyano-nitride of titanium, of the formula $TiCy + 3Ti^3N$.[9] Wollaston had long previously examined it and pronounced it pure titanium. According to Karsten traces of titanium exist in very many varieties of cast-iron; but it is questionable whether in such cases the metal be actually alloyed with, or dissolved in, the iron, and whether it be not in the state of mechanically diffused cyano-nitride. In the iron constituting the "bear" it may exist in a very finely divided state, as may be proved by the action of acids upon a titaniferous "bear," which dissolve the iron and leave the titanium compound.

Faraday and Stodart failed in their attempts to introduce titanium into steel. A mixture of steel-filings and oxide of titanium (TiO^2), with a little charcoal, was intensely heated, when the steel fused, and ran into a fine globule which was covered with a fine glass, adhering to the sides of the crucible: the steel contained no titanium. The temperature employed was sufficient to soften and almost liquefy the crucibles in fifteen minutes.[1] In one experiment menachanite was used: the button contained "not an atom of titanium;" it, however, received a fine damask surface.[2]

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[8] Recherches sur le Titane et son affinité spéciale pour l'Azote. Par MM. F. Wöhler et H. Sainte-Claire Deville. Ann. de Chim. et de Phys. 3. s. 52. p. 92. 1858.

[9] Ann. de Chim. et de Phys. 3. s. 29. p. 166. 1850.

[1] Quarterly Journ. ante cit. p. 322.

[2] Phil. Trans. ante cit. p. 267.

Karsten states that traces of titanium occur in very many kinds of cast-iron.[3] Mr. Riley has of late been actively engaged in searching for titanium, and he has succeeded in finding it, especially in fire clays; he has failed to detect it in many specimens of malleable iron and cast-iron in which its presence was suspected, but quite recently he has discovered it in sensible quantity in certain varieties of the latter.

The following experiment has been made by Mr. Hochstätter in my laboratory. Of nearly pure artificially prepared sesquioxide of iron 125 grains were mixed intimately with 127 grains of powdered rutile (TiO^2), and the mixture was exposed in a covered brasqued crucible during 1½ hour to a white heat. The product was partly fused and partly fritted. The external surface was copper-red in colour. The whole was reheated to whiteness during 1¼ hour in a covered brasqued crucible, with the addition of 40 grains of lime and 60 grains of plate glass. This second product was imperfectly melted, but contained numerous globules of metal diffused. These were greyish white in fracture, only slightly malleable, and strongly magnetic. They dissolved slowly in boiling hydrochloric acid, with the exception of a little black residue, which disappeared completely by ignition in contact with air. No trace of titanium was detected in the globules by precipitating the solution of them in nitrohydrochloric acid by ammonia, redissolving the precipitate in cold sulphuric acid, subsequently boiling the solution thus obtained during a long time, when not the slightest precipitate appeared, as would have been the case if titanium had been present in sensible quantity.

During the period comprised between March, 1859, and December, 1861, not fewer than thirteen patents have been granted to Mr. Robert Mushet for alleged improvements in the manufacture of iron and steel, and in all the application of titanium plays the chief part. To wade through such a mass of printed matter is, as may well be conceived, a rather tiresome operation. In the first patent[4] the use of titanium is claimed in alloy with cast-steel; and in the second[5] the direct production of titaniferous steel by melting together malleable iron, charcoal, and certain titaniferous matters. In the third patent[6] the claim is as follows: "The essence of my invention consists in melting blister-steel, bar or puddled steel, or scrap-steel, or mixtures of these varieties of steel, or a mixture of malleable iron and carbonaceous matter in such proportions as will produce steel, or any material or mixture of materials which, when melted, produces cast-steel with New Zealand or other iserine, or titaniferous iron-sand and carbonaceous matter, or adding the said titaniferous iron-sand and carbonaceous matter to the steel, or to the mixture of malleable iron and carbonaceous matter, or to the steel-producing materials, which it is intended to melt into cast-steel during the melting of the said steel, or the said

[3] l. p. 534.
[4] A.D. 1859, March, No. 703.
[5] A.D. 1859, May, No. 1115.
[6] A.D. 1860, Sep. 29, No. 2365. "An improvement in the Manufacture of Cast-steel."

malleable iron and carbonaceous matter, or the said steel-producing materials, or after the said steel or malleable iron and carbonaceous matter, or the said steel-producing materials, are melted and reduced to a liquid state; and, lastly, in adding to highly carbonized steel New Zealand or other iserine, or titaniferous iron-sand, without additional admixture of carbonaceous matter, and melting the said highly carbonized steel and the titaniferous iron-sand together in a melting-pot or crucible. In this case the excess of carbon contained in the said highly carbonized steel suffices, in place of any further addition of carbonaceous matter, to reduce the iserine or titaniferous iron-sand, either partially or wholly, to the metallic state."

The title of the fourth patent is "An Improvement or Improvements in the Manufacture of an Alloy or Alloys of Titanium and Iron."[7] The patentee states that the essence of his invention consists in obtaining from iserine or titaniferous iron-sand an alloy or alloys of titanium and iron by smelting this mineral, after previous admixture with certain resinous or bituminous matters in a blast-furnace or cupola by preference supplied with hotblast. The reduced metal, it is alleged, is an alloy of iron and titanium, containing also carbon. Charcoal is recommended as the fuel when the metal is intended to be used for alloying cast-steel.

The fifth patent[8] has the same title as the fourth, and the essence of the invention "consists in smelting the compound ores of titanium, termed by mineralogists ilmenites, and commonly called titaniferous iron ores, or iron ores rich in titanium," with a view to obtain a titaniferous alloy of iron, containing also carbon.

The sixth patent[9] is for "improvements" on former patents concerning the application of titanium to cast-steel.

The seventh patent[1] is for "improving the quality of such malleable iron, semi-steel, or cast-steel, as are manufactured by passing or forcing air through pig-iron or cast-iron" while in a molten state. The object of this "invention" was clearly to prohibit Bessemer from adding any titaniferous matter to the molten product, whether iron or steel, obtained in his process.

. The "invention"[2] claimed in the eighth patent is stated to consist, "firstly, in adding to steel, or to any mixture of materials which when melted produces cast-steel, a mixture of granulated pig-iron, cast-iron, or refined iron, and pulverised titanium ore, titaniferous iron ore, titanic acid, or oxide of titanium, and melting the said steel or steel-producing materials and the said mixture of granulated pig, cast, or refined iron, and pulverised titanium ore, acid, or oxide, together in the said melting-pot or crucible, in order to alloy the titanium or a portion of the titanium contained in the said titanium ore, acid, or oxide with the cast-steel melted from the steel or from the mixture of steel-producing materials operated upon, so as to produce thereby an

[7] A.D. 1860, Dec. 8, No. 3010.
[8] A.D. 1860, Dec. 10, No. 3030.
[9] A.D. 1860, Dec. 12, No. 3045.
[1] A.D. 1860, Dec. 13, No. 3070.
[2] A.D. 1861, Jan. 21, No. 163.

improved quality or qualities of cast-steel;" and, secondly, "in adding to steel, or to any mixture of materials which when melted produce cast-steel, a mixture of granular pig, cast, or refined iron and metallized deoxidized ilmenite or compound ore of titanium and iron, and melting the said steel or the said steel-producing materials, and the said mixture of metallized deoxidized ilmenite or compound ore of titanium and iron, and granular pig, cast, or refined iron together in a melting-pot or crucible, in order to improve the quality of the cast-steel obtained."

The invention specified in the ninth[3] patent consists essentially in melting spiegeleisen, or some other similar compound, with cast-steel, especially with a view of counteracting red-shortness, or otherwise improving the quality. The patentee includes "grey" spiegeleisen.[4] This is probably a misnomer; for if it were grey, it would cease to be spiegeleisen.

In the tenth[5] patent, the smelting of titaniferous ores in conjunction with red hæmatite is claimed, whereby an "improved titanic pig-metal" is produced, which, it is alleged, "possesses a specific excellence of quality and a specific adaptation for the purpose of manufacturing therefrom first-class steel and iron, not possessed by any other alloy of titanium and iron containing also carbon," so far as the patentee is aware.

In the eleventh[6] patent the exclusive right is conferred of manufacturing a triple metallic compound or alloy of iron, titanium, and manganese, containing also carbon.

In the twelfth[7] patent is granted the exclusive privilege of alloying cast-steel or "homogeneous iron" with the triple alloy specified in the last patent. This alloy, according to the experience of the patentee, usually contains a little silicon; but the quantity of this is so small as not to prove "in the least degree hurtful" to the quality of the cast-steel or homogeneous iron into which it may enter.

The essence of the invention in the last or thirteenth[8] patent consists in adding "titanic pig-metal" to ordinary pig-iron, cast-iron, or refined iron, or any mixture of these, in a puddling-furnace, with a view to improve the quality of the malleable iron, bar-iron, or puddled steel which may be produced from such mixtures.

If the faith of a patentee in the value of an "invention" is to be measured by the number of patents which he takes out in order to secure it wholly to himself, then has Mr. Mushet displayed an inordinate amount of this Christian virtue. Thirteen patents to one man for the application of titanium in one form or other to the manufacture of iron and steel is a somewhat remarkable incident even in the annals of patentism! The "titanic steel" thus appropriated with such Titanic force of law should, indeed, be worth something to Mr. Mushet and the world. Every means has been adopted to proclaim its unri-

[3] A.D. 1861, Feb. 23, No. 473.
[4] Specification, p. 12.
[5] A.D. 1861, Oct. 19, No. 2609.
[6] A.D. 1861, Oct. 22, No. 2637.
[7] A.D. 1861, Nov. 1, No. 2744.
[8] A.D. 1861, Dec. 12, No. 3116.

valled excellence far and wide. Newspapers and journals have been laid under contribution with this view; and in London, Birmingham, and elsewhere articles of "titanic steel" have been profusely displayed in conspicuous shops with large signboards. This is all right and according to custom. But, it may be asked, has the public, so easily credulous in most things, yet shown its appreciation of this important metallurgical invention? Some analytical chemists of skill and repute declare that they have examined specimens of "titanic steel" without being able to detect any titanium in it. Titanium in minute quantity in iron is not easily detected, so that negative evidence of this kind may have proceeded from the imperfection of the method of analysis. Or the specimens operated on may have been exceptional, as in the case of some commercial articles of wolfram steel, which, according to Wagner, contained not a trace of tungsten. On inquiry I learn that Mr. Mushet has not yet succeeded in convincing the Sheffield steel-makers of the surpassing excellence which he claims for his "titanic steel." This may be due to prejudice, or it may be the result of honest conviction, which is the most probable. My friend, Mr. Webster, writes as follows: "That manufacturers should be slow to adopt a change is only natural; the simplest and greatest discoveries have to overcome the conservative resistance to change, a resistance bearing in general some proportion to the importance of the result, or the consequences of the invention."[9] It is to be hoped that the "titanic steel" may ultimately prove to belong to this category!

Iron and Lead.

By reducing a mixture of minium and oxide of iron with black flux, Rinmann obtained lead which he believed to be ferriferous: it was harder than ordinary lead. He concluded that by this means lead might dissolve a little iron, but that iron would not take up any lead. He could not produce an alloy of these metals in any proportion by directly heating them together in the metallic state;[1] nor could Karsten. The metallic mass always consists of two layers, the upper one of iron and the lower one of lead. But on reducing litharge with excess of pure iron at a very high temperature, Karsten obtained melted iron in which he found, as the average of several experiments, 2·06% of lead. The alloy had a coarsely foliated fracture, and was brittle, but not in the least degree hard. It could be flattened out somewhat, but not without cracking at the edges. When, however, reduction of the litharge was effected with cast or carburized iron, the button of iron was free from lead.[2] Sonnenschein has published the following account of an alloy of iron and lead from a blast-furnace at the Marienhütte, Upper Silesia, where plumbiferous brown iron ore was smelted. After the furnace had been in operation about five years,

[9] The Case of Josiah Marshall Heath, the Inventor and Introducer of the Manufacture of Welding Cast-steel from British Iron. By Thomas Webster, M.A., F.R.S., Barrister-at-Law. London, 1856, p. x.

[1] Geschichte des Eisens, 1. p. 508.

[2] Eisenhüttenkunde, 1. p. 506.

lead ate through under the hearth sideways about six inches below the tap-hole, and at every tapping lead flowed along with the cast-iron. Consequently below the tap-hole a small cavity was formed in which the lead might collect, and which was emptied several times in the twenty-four hours. In the course of eighteen months 526 cwts. of lead were thus obtained. After the furnace had been at work during seven years, it was blown out. On breaking it up, not only was much lead found in the "bear," but also various aggregations of crystals, some of which were erroneously regarded as cyano-nitride of iron from their appearance. These crystals were cubes, which were here and there placed upon each other like steps; but there were also groups of acicular plumose crystals, having the following characters:—Their colour for the most part was brass-yellow, but in certain places it was a peculiar glittering blue. They were soft, rather harder than lead, but could be easily cut, and their cut surface had a leaden lustre. Their specific gravity was 10·560, and they were strongly attracted by the magnet. From several analyses, these crystals were found to consist of 88·76% of lead and 11·14% of iron, which corresponds to the formula 2Pb+Fe. Their calculated composition is 88·08% of lead and 11·92% of iron. Sonnenschein suggests that this interesting alloy may have been formed by the long-continued action of gaseous lead upon metallic iron. The red crystalline groups above mentioned were partly surrounded with minium; the crystals were cubes or varieties of cubes, having a vitreous lustre; they were pure lead, coated superficially with an extraordinarily thin layer of red oxide.[3] Mr. Dick, who has been long engaged in lead-smelting, informs me that the iron of the large perforated ladles, used in Pattinson's desilverization process, becomes in the course of time thoroughly permeated with lead.

Biewend, of Clausthal, has described an alloy prepared by heating in a brasqued crucible a slag rich in lead and iron. Most of the lead was volatilized. The alloy had been well melted, was hard and brittle, only admitting of being slightly flattened under the hammer without cracking; the fracture was finely granular-foliated (*kleinkörnig-blätterig*), shining, and between steel-grey and tin-white in colour. It consisted of 96·76% of iron and 3·24% of lead.[4]

We have repeated Karsten's experiment of reducing litharge with iron, but have not succeeded in confirming his results. We have employed wrought-iron, as well as clay, crucibles; the latter are immediately corroded and perforated by the oxide of iron produced, if not previously by the litharge itself. We have endeavoured in vain to obtain an alloy similar to that of Sonnenschein, or indeed any other decided alloy of iron and lead.

Iron and Antimony.

These metals readily unite by fusion, producing hard, brittle, white, easily fusible alloys, of lower specific gravity than the mean of

[3] Chem. Gaz. 14. p. 434. 1856. [4] Journ. f. prak. Chem. 23. p. 252.

the specific gravities of the component metals. It is stated that antimony tends in a greater degree than any other metal to destroy the magnetic property of iron. According to Berthier the alloy containing 70·5 % antimony, *i.e.* Fe+Sb, is undecomposable at the highest temperature; and alloys with a greater proportion, at 150° (Wedgwood's pyrometer) lose antimony until the residuum acquires this formula.[5] An alloy of 1 part by weight of antimony and 2 of iron strikes fire when filed.[6]

The following experiments have been made by Mr. Richardson in my laboratory. Commercial antimony and thick iron wire were used. Fusion was effected in clay crucibles with luted covers.

I. Iron 224 grs., antimony 258, corresponding to the formula Fe^4Sb. A well melted button was obtained, weighing 479 grs., showing a loss of 3 grs. It was dull grey, brittle, and granular in fracture.

II. Iron 200 grs., antimony 200 grs. A well melted button was obtained, weighing 390 grs., showing a loss of 10 grs. It was similar in characters to the last.

III. Iron 297 grs., antimony 3 grs. A well melted button was obtained, weighing 292 grs., showing a loss of 8 grs. It was not quite so brittle as the buttons in Nos. I. and II.; it had a brighter lustre, but was similar in fracture.

Karsten ascertained the effect of the addition of 1 % of antimony to the charge of cast-iron during the process of conversion into malleable iron in the charcoal hearth. Notwithstanding its volatility, it acted far more injuriously than the addition of the same amount of tin. At a white heat, it occasioned the same "smoking" of the iron as tin; but the bar-iron was far more fragile, and was extremely cold as well as red-short. The bar-iron contained 0·23 % of antimony. Karsten detected 0·114 % of antimony in bar-iron which was so cold-short as to be worthless; he found, besides, only an inappreciable amount of sulphur and 0·38 of phosphorus, which, according to his experience, was inadequate to produce cold-shortness in a sensible degree. He regarded the presence of this minute quantity of antimony as amply sufficient to account for the bad quality of the iron in question.

Iron and Bismuth.

Amongst the old metallurgical writers there was great discordancy of opinion on this subject, some asserting that these metals alloyed readily together, and others that they would not unite at all. Karsten found that the addition of 1 % of bismuth to the charge in converting cast into malleable iron in a charcoal-hearth had no effect on the quality of the iron produced. However, it worked somewhat "raw," and this was the only defect. As soon as the cast-iron began to melt, bluish green flame and smoke were evolved, which lasted more than half an hour. The bar-iron made contained 0·081 % of bismuth.[7]

[5] Tr. 2. p. 217. [6] Thenard, Tr. de Chimie, 2. p. 247. 1834. [7] 1. p. 522.

IRON AND NICKEL.

Faraday and Stodart melted these metals together in several proportions, and found them to alloy well. Their results are as follow :[8]

1. Horseshoe nails were melted with 3 % of pure nickel. The alloy, it is stated, was quite as malleable and pleasant to work under the hammer as pure iron. When polished it was rather whiter than iron. Its specific gravity was 7·804, and that of the hammered alloy of steel with 3 % of nickel was 7·750.

2. Horse-shoe nails were melted with 10 % of nickel. The metals were perfectly combined, but the alloy was less malleable, and more disposed to crack under the hammer. When polished it had a yellow tinge. Its specific gravity was 7·849, and that of steel alloyed with 10 % of nickel was 7·684. This alloy rusted less quickly than pure iron; but it was found that the presence of nickel in iron did not prevent oxidation to the extent previously alleged. The same quantity of nickel alloyed with steel, instead of preventing, accelerated rusting very rapidly.

Berthier states that iron and nickel very easily alloy together in all proportions, and that the alloys have the same properties as pure iron, but are whiter. He describes an alloy containing 8·3 % of nickel, *i. e.* $Fe^{12}Ni$, which he prepared by the reduction of the mixed oxides of iron and nickel in a brasqued crucible: it was semi-ductile, very tenacious, and fine-grained, but somewhat scaly in fracture. This composition is the same as that of a meteoric iron from near Bogotá.[9]

The following experiments on alloys of iron and nickel have been made in my laboratory by Mr. Richardson. The nickel was that manufactured by Evans and Askin, Birmingham, and which may be regarded as practically pure. The iron was in the state of fine wire. Fusion was effected under plate-glass in clay crucibles. The metals appeared to alloy perfectly together.

1. With 1 % of nickel. Iron 495 grs. and nickel 5 grs. A well melted button was obtained, which weighed 490 grs., thus showing a loss of 10 grs.; its surface was partially coated with thin black scale. When cut about half through with a cold chisel the remainder broke; the fracture appeared in all respects similar to that of a button of iron after fusion *per se*.

2. With 5 % of nickel. Iron 285 grs. and nickel 15 grs. The loss was 10 grs. The alloy seemed to be perfectly made. The surface of the button was generally thinly coated with black scale. It was more brittle than that of No. 1. The fracture was bright and finely granular, but had not the bluish-grey tinge of iron.

3. With 20 % of nickel. Iron 240 grs. and nickel 60 grs. The loss was 20 grs. The surface of the button was smooth, and everywhere free from scale. The alloy was brittle, and, on cutting across with the chisel in the usual manner, broke with an extremely irre-

[8] Quarterly Journ. ante cit. p. 324. [9] Traité, 2. p. 216.

gular fracture, of which it is difficult to give an accurate notion by description. It might be described as fibro-columnar, and under a lens both in the direction of, and across, the fibrous bundles the metal appeared minutely granular. Its lustre was dull. The colour of the freshly-scraped surface of the button was bluish-white, but previously it had a yellowish tinge. Its specific gravity was 7·917.

4. With 50% of nickel. Iron 200 grs. and nickel 200 grs. The loss was 20 grs. The external appearance of the button resembled that of No. 3; it was smooth, free from scale, dull, and had a yellowish tinge due to superficial tarnish; after scraping, in colour it appeared very similar to the last. It flattened sensibly under the hammer, but was, nevertheless, brittle. The fracture obtained in the usual manner was quite different from those of the foregoing alloys; it was even, uniform, and finely granular, much like that of cast-steel; but on observing it under varying directions of incident light, it seemed to consist of an aggregation of shining points, such as I have not remarked in an equally fine-grained fracture of cast-steel. Its specific gravity was 8·200.

All these alloys strongly attracted the magnetic needle, and the last two were susceptible of high polish: both clogged the file.

Pieces of each of these two alloys having been filed and polished, were left for several days in contact with very dilute sulphuric acid, but no damask appeared.

Longmaid has patented the alloying of iron with nickel in proportions never exceeding 4 ozs. of the latter to the ton.[1] The nickel is added during the processes of refining or puddling. The iron thus produced "will," it is declared, "be greatly improved in quality." Although this declaration may be made *bonâ fide*, yet it should be remembered that it is only an opinion of an interested patentee.

Liebig examined alloys of nickel with iron and steel, prepared by Wolf, of Schweinfurth, whom he praises highly as a manufacturer. The nickel-steel had the aspect and properties of genuine Damascus steel, and the nickel-iron acquired likewise by the usual process a magnificent damask.[2]

Mr. Fairbairn has recorded the results of "Experiments to determine the strength of some alloys of Nickel and Iron, similar in composition to Meteoric Iron."[3] In the first series the nickel employed was obtained from a nickeliferous ore by a dry process, the rationale of which I do not understand; nor should I if the nature of the ore had been described. Cast-iron, No. 3, Blaenavon pig, and not malleable iron, was used in making these alloys. As no evidence is given concerning the purity of the nickel, the results of these experiments are valueless. In a second series of experiments "perfectly pure nickel" is stated to have been used with cast-iron, as before. The strength of the cast-iron was very sensibly diminished by the addition

[1] A.D. 1861, No. 1863.

[2] Annalen der Pharmacie, 2. p. 237. 1832.

[3] Proceedings of the Manchester Philosophical Society, March 9, 1858.

of $2\frac{1}{2}$ % of nickel; the strength of Blaenavon pig-iron being estimated as 100, that of the alloy was, on the average of six experiments, 83. The nickel also greatly reduced the power to resist ultimate deflection and impact.

IRON AND COBALT.

According to Hassenfratz iron alloyed with cobalt is very malleable and weldable, is not cold-short, but is somewhat inclined to be red-short.[4] But it is only recently that pure cobalt has been produced in quantity, and there is no certainty that in former times the impure metal was not employed in the experiments recorded concerning its alloys. Arsenic especially was likely to be present. Berthier ascribes exactly the same characters to the alloys of iron and cobalt as to those of iron and nickel; but it may be doubted whether he had made sufficient experiments to justify such a general conclusion.

The following experiments have been made in my laboratory by Mr. Smith. Nearly pure hæmatite and protoxide of cobalt were used. The quantities taken in grains were—

	I.	II.
Hæmatite	200	360
Protoxide of cobalt	200	40
Charcoal powder	100	100

The mixed ingredients were put into a charcoal-lined plumbago crucible, the cavity filled up with a mixture of china clay and lime, the pot luted over, and exposed to a white heat for 2 hours.

Ex. 1. Result. A well fused button with globules, weighing 296 grs., attracted by the magnet; flattens somewhat under the hammer, and then breaks; fracture granular, bluish grey with feeble lustre. Slag, a transparent glass of a pale greenish blue tint.

Ex. 2. Result. A well fused button with a few globules, weighing 286 grs., attracted by the magnet; breaks under the hammer; fracture centre portion granular, greyish white, surrounded with a very thin layer, fine grained, dull and dark grey in colour. Slag as in 1.

The buttons had the following per centage composition:—

	I.	II.
Iron	46·71	87·21
Cobalt[5]	53·29	12·79

Both alloys when finely powdered are decomposed with facility by hydrochloric acid with evolution of fetid hydrogen.

If the hæmatite contains 70 % of iron, and the protoxide of cobalt 78·5 % of cobalt, and the whole of the metal separated without taking up carbon, the buttons should weigh 297 and 283·4 grs. respectively, and contain 47·1 % and 88·3 % of iron—the respective formulæ approximating to FeCo and Fe^8Co.

[4] Karsten, 1. p. 532.

[5] By difference, and inclusive of carbon present, but not determined.

Iron and Mercury.

Iron is not in the least acted upon by mercury, whether cold or hot. Several indirect processes have been described for amalgamating iron with mercury; but in some of these it is doubtful whether true amalgams are formed. Through the intervention of a third metal the tendency of the mercury to unite is promoted. Thus, when a piece of iron with a surface well cleaned by "dipping" is plunged into an amalgam of potassium, its surface becomes coated with firmly adherent amalgam; but the mercury separates completely as the potassium oxidizes by exposure to the air, leaving the iron quite as bright as before the operation.[6] Joule has described a definite amalgam of the formula $Fe+Hg$, which he prepared by electrolysis of a solution of iron with mercury as the negative electrode. The superfluous mercury was expelled in a special apparatus under a pressure of 60 tons to the square inch.[7] Schönbein prepares an iron amalgam by rubbing together a concentrated solution of protochloride of iron with mercury containing 1 % of sodium. The thickish iron-amalgam thus formed is washed thoroughly with water until it is perfectly pure.[8] According to Böttger a pure, strongly magnetic amalgam of iron may be obtained by triturating intimately together in a porcelain mortar 2 parts by weight of crystallized chloride of mercury and 1 of finely divided iron, with the addition of 2 parts of cold water, stirring all the while, and also of a few drops of mercury at the moment when heat begins to be strongly evolved.[9] Cailletet states that iron becomes superficially amalgamated by the action of the amalgam of ammonium or sodium, or when immersed in acidulated water in contact with mercury forming the negative pole of a galvanic battery.[1]

For the following statement I am indebted to my friend Mr. William Crookes, by whom the information was obtained.

When crystallized sodium amalgam is covered with a saturated solution of protosulphate of iron, the latter metal in the course of an hour or two changes place with the sodium, and iron amalgam is formed. This is strongly agitated with dilute hydrochloric acid, which removes any sodium which may remain, and the amalgam of iron is left as a soft unctuous feeling mass of the consistency of butter, in colour intermediate between mercury and iron. This appears to be a mixture of a solid amalgam with mercury. Upon squeezing the mass in chamois leather liquid mercury separates, and there is left behind a solid steel grey crystalline lump, which upon analysis was found to contain 12·77 % of iron ($FeHg_2$ requires 12·28 %). If this solid iron amalgam is kneaded with the fingers in the palm of the hand, it gradually gets unpleasantly hot, and after a little time separates into globules of metallic mercury and black pulverulent iron. The same change takes

[6] Berzelius, Tr. 2. p. 708.

[7] Brit. Assoc. Rep. Edinburgh, 1850. Transactions of the Sections, p 55.

[8] Jahres-Bericht, L. and K., 1861, p. 95.

[9] Jahresb., L. and K., 1857, p. 224.

[1] Jahresb. ante cit. 1857, p. 249.

place more slowly when the cake of solid iron amalgam is left exposed to the air; the mercury being occasionally projected from it in jets an inch or more in length. The heat evolved is not due to the oxidation of the iron, as the same change takes place with separation of the same black powder when the amalgam is hermetically sealed in a tube containing mineral naphtha. Both the solid and liquid amalgam, as well as the liquid mercury squeezed from them, are strongly magnetic. The iron in all gradually oxidizes on exposure to the air, coating the surface with a film of red oxide. When the amalgam is of a buttery or weaker consistency, it does not appear to decompose spontaneously.

Iron and Silver.

As usual, the opinions of the earlier metallurgists as to the alloys of iron and silver are extremely discordant, some maintaining that they unite readily and perfectly by fusion, and others that iron and silver only take up very small proportions of each other respectively. Coulomb states that silver can only retain about $\frac{1}{150}$ of iron, and Morveau that iron cannot retain more than $\frac{1}{80}$ of silver.[1] The first of these observers found that silver with only $\frac{1}{350}$ of iron acted upon the magnetic needle; and that silver reduced from horn-silver (fused Ag Cl) disturbed the needle, even when it contained only 1 of iron to 133119 of silver. Large wrought-iron crucibles have been employed during many years for melting silver, which sufficiently proves that at the temperature of molten silver there can be no very marked affinity between the two metals.

We are indebted to Karsten for experiments on the large scale to determine the effect of silver upon the workable qualities of iron. Bar-iron made in the charcoal finery from pig-iron, to which $1\frac{1}{2}$ % of fine silver had been added, was found to be deteriorated by this addition. A bluish-green vapour was evolved from the metal during the process of conversion, and also from the bar-iron during hammering, so long as it remained white-hot. The iron was unsound, laminar, and very red-short; it gave by analysis 0·034 % of silver. Silver produced the same action upon iron as sulphur, though in a somewhat less marked degree.

Mr. Longmaid has recently patented alloying iron with homœopathic doses of silver.[2] The quantity of silver, the patentee has ascertained, should never exceed 10 ozs. to the ton of iron; but for general purposes he prefers that it should not exceed 1 or 2 ozs., only increasing the proportion when he wishes to make the iron stronger and more ductile, or suitable for conversion into steel. The silver may be added during the operations of refining or puddling. He informs us that he has "found a marked improvement in the manufacture of iron is obtained when using less than an ounce of silver to the ton of iron;" and he remarks that he is "aware silver has before been used to alloy

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[1] Karsten, l. p. 491.

[2] A.D. 1861, July 24th, No. 1863. "Improvements in the manufacture of iron."

iron, but the quantities applied have been so large as to prevent the desired qualities of iron being produced, and the whole of the silver has not been so chemically combined as when using minute quantities." Mr. Longmaid's patent has not, I believe, secured the favourable consideration of ironmasters; and I should be surprised if it had. In experimenting on the puddling furnace the utmost caution is necessary in order to avoid erroneous conclusions. Even in two successive "heats" it is difficult to ensure anything like identity of conditions. A little more attention, or a little more well-directed labour, commonly termed "elbow grease," on the part of the puddler, in one "heat" as compared with the other, may occasion marked difference in the result. In experiments of this nature pretty good fees are usually slipped into the hands of the workman, whose interest it then becomes by hook or by crook to attain the end desired by the experimenter. I have seen a Welsh puddler present his employer,—who was engaged in attempts to improve the quality of iron by a very stupid process,—with a bar of iron of first-rate quality, which he declared was produced from remarkably bad pig-iron, and the excellence of which he ascribed entirely to the supposed improvements!

Faraday and Stodart melted silver and steel together, and obtained the following results.[4] When a mixture of these metals is kept long in a molten state, a perfect alloy seems to be formed; but on solidification globules of pure silver appear on the surface of the button, having been squeezed out from the interior. When a forged bar of this metal is acted upon by dilute sulphuric acid, the silver is left in threads through the mass, "so that the whole has the appearance of a bundle of fibres of silver and steel, as if they had been united by welding." The fibres are sometimes $\frac{1}{8}$ in. long. After very long exposure to a high temperature the sides and top of the crucible were coated with a dew of minute globules of silver. Silver and steel were fused together in various proportions, as under:

(1.) Silver 1 and steel 160. The buttons consisted of steel and silver in fibres. Globules of silver adhered to the surface of the buttons, of which some on forging gave out more globules. Bars of this mixture were rapidly oxidized in moist air. (2.) Silver 1 and steel 200. Fibres and globules in abundance. (3.) Silver 1 and steel 300. Fibres diminished, but still present. (4.) Silver 1 and steel 400. Fibres still detected. (5.) Silver 1 and steel 500. A perfect button was obtained without any appearance of silver on its surface, or deposit of dew of silver on the sides and cover of the crucible; and no fibre could be detected in a forged bar after dissection by an acid, not even with the aid of a high magnifying power. The metal, although very hard, forged remarkably well, and was pronounced "decidedly superior to the very best steel." The superiority was ascribed to "combination with a minute portion of silver," which was found to be present in every part of the bar. A trial on a larger scale was made by melting 8 lbs. of "very good Indian steel" with

[4] Quarterly Journ. of Science, Literature, and the Arts, 9. p. 325. 1820.

$\frac{1}{500}$ of its weight of pure silver. The ingot "presented a most favourable appearance both as to surface and fracture; it was harder than the best cast-steel, even than the Indian wootz, with no disposition whatever to crack, either under the hammer or in hardening."[5] Faraday and Stodart formed a much higher opinion of the value of this alloy than experience has justified. They attempted to alloy steel and silver by cementation, but did not succeed. A small piece of steel wrapped up in silver leaf in the proportion of 160 : 1 was put into a crucible, which was then filled with pounded green glass, and kept during three hours at a white heat. The silver was found fused and adhering to the steel; but no part had combined.

Iron and Gold.

Gold and iron may be readily alloyed together. It was formerly believed that the ductility and malleability of gold were much diminished, if not destroyed, by the addition even of a very small quantity of iron, until Hatchett proved by the following experiments that this belief was erroneous:[6]—

1. Fine gold was melted with 8·3% of clean iron wire, and the whole, after well mixing, was cast into a bar in a greased mould of iron. The alloy had a pale yellowish grey colour, approaching dull white; it was very ductile, and by rolling was with great ease reduced from the thickness of ¼ inch to that of a guinea; it was then readily punched into blanks, which were stamped with great facility, though not previously annealed.

2. Fine gold was melted with 8·3% of thin plate cast-steel, which was added to the molten gold. The alloy in all respects closely resembled the former.

3. Fine gold was melted with 8·3% of cast-iron in the form of nails. The experiment was made in the same manner, and the alloy had the same characters as that of No. 2.

The conclusion which Hatchett drew from these results is that gold "made standard" with iron, steel, or cast-iron, *i. e.* alloyed in the proportion of 22 of gold to 2 of any one of these metals, is not rendered brittle, though its hardness is increased, as it might be even hammered, rolled, and stamped without annealing.

According to Faraday and Stodart, gold forms a good alloy with steel.[7] They made no experiments on this alloy in the large way, and were doubtful as to its value. The specific gravity of a hammered alloy of steel with 1% of gold was 7·870.

Iron and Platinum.

Iron and platinum appear to alloy well together, as every analytical chemist must be well aware, who, in heating any compound of iron in a platinum crucible, has had the iron accidentally reduced. The iron

[5] Phil. Trans. 1822, p. 257.
[6] Ibid. 1803, p. 37.
[7] Quarterly Journ. ante cit. p. 329.

lays firm hold of the platinum, and generally every attempt to remove it by boiling with hydrochloric acid, fusion with bisulphate of potash, etc., will prove fruitless. By such treatment the surface may be rendered perfectly bright; but on reheating to redness the presence of iron is manifested by the blackening of that part of the interior where the alloy exists. That a knowledge of the action of iron on platinum at high temperatures may not be unimportant to ironmasters is proved by the fact, that not long ago a steel-manufacturer in a published lecture on iron suggested the possibility of substituting platinum for iron in the beds of puddling furnaces![8]

According to Faraday and Stodart steel and platinum alloy well together in all proportions, and platinum will fuse in contact with steel at a temperature at which even the steel itself is not affected: they obtained the following results:[9]—

1. Steel 50 and platinum 50. The alloy is described as beautiful, and as possessing the "finest imaginable" colour for a mirror; it takes a high polish, is malleable, does not tarnish, and has a specific gravity of 9·862.

2. Steel 20 and platinum 90. A perfect alloy was obtained, which was malleable, showed no tendency to tarnish, and had a specific gravity of 15·88.

3. Steel 80 and platinum 10. The alloy was pronounced excellent. It was ground and very highly polished, but proved unfit for mirrors owing to the fine damask of its surface. This alloy, after lying exposed during many months, had not a spot on its surface; whereas an alloy of steel and nickel in the same proportions had become covered with rust after similar exposure. The specific gravity of steel alloyed with 10 % of platinum was 8·100, and that of a hammered alloy of steel with 1·5 % of platinum was 7·732.

Wires of steel and platinum of about equal diameter were packed together and found to weld perfectly and with as much facility as steel and iron. By slightly acting with an acid upon the polished surface of a bar thus produced and forged, "a very novel and beautiful surface appeared, the steel and platinum forming dark and white clouds." Some of the largest of the steel clouds appeared to consist of an alloy of the two metals resulting from cementation.

Larger experiments were made at Sheffield under the instructions of Faraday and Stodart: 10 lbs. of good Indian steel were melted with $\frac{1}{100}$ of spongy platinum. The bars were remarkable for smoothness of surface and beauty of fracture. The alloy was less hard, but much tougher, than the alloy of 8 lbs. of steel with $\frac{1}{500}$ of silver. It is rapidly acted upon by dilute sulphuric acid.[1] If a piece of steel and one of the platinum alloy are immersed in the same weak sulphuric

[8] Extracts from Miscellaneous Observations on the Manufacture of Iron, etc. By Richard Solly, of the Leabrook Iron Works, Staffordshire, and of Sheffield. A paper read before the Geological and Polytechnic Society of the West Riding of Yorkshire. "Platinum might probably answer, if it should ever become abundant and cheap enough" (p. 11).

[9] Quarterly Journ. ante cit.

[1] Phil. Trans. ante cit. p. 257.

acid, in equal periods, the latter will evolve some hundreds of times more gas than the former. Steel acquires this property when alloyed with a very small quantity of platinum : $\frac{1}{400}$ increased the action considerably; with $\frac{1}{200}$ and $\frac{1}{100}$ it was powerful; with 10 % the action was not very powerful; with 50 % it was not greater than with steel alone ; and an alloy of 90 of platinum and 20 of iron was not affected by the acid. When two portions of the platinum alloy, one hard and the other soft, are left for some hours in the same dilute sulphuric acid, the hard piece becomes coated with "metallic black carbonaceous powder, and the surface is generally fibrous;" whereas the soft piece becomes thickly coated with "grey metallic plumbaginous matter, soft to the touch," easily sectile, and in amount exceeding by seven or eight times that on the hard piece. The powder from the soft alloy, when it has not remained long in the acid, exactly resembles finely divided plumbago; owing to the presence of iron, it oxidizes by exposure to the air and becomes discoloured. After remaining long, or boiling, in the acid, it is reduced to the same state as the powder from the hard steel alloy. By the action of nitric acid, a black residuum is produced, which, after careful washing and drying, is strongly explosive. It contains much platinum and very little iron. Wrapped in foil and heated, it explodes with much force, tearing open the foil and emitting a faint light. Dropped on the surface of heated mercury, it exploded readily at 204·4° C. (400° Fah.), but with difficulty at 187·7° C. (or 370° Fah.). When the temperature was slowly raised, it did not explode, but was quietly decomposed. Detonated at the bottom of a hot glass tube, much water and fume were given off, and the residuum consisted of metallic platinum with very little iron and carbon.

A patent has recently been granted to William Longmaid for "Improvements in the Manufacture of Iron and Steel."[a] They consist essentially in alloying iron or steel with "minute quantities" of gold or platinum, or of both together. The patentee assures us "that the use of from $\frac{3}{16}$ to $\frac{5}{16}$ of an ounce of gold or of platinum, or of the two together, materially improves the density, ductility, and tenacity of the iron or steel." What is meant by improving the density is not very clear. The patentee has produced a very sonorous bell-metal by adding as much as 3 ozs. of gold to the ton of an alloy of iron; but with this exception, he has not found it desirable to introduce more than ½ oz. of gold or platinum, or of the two metals together, to each ton of iron or steel. For ordinary castings, he adds about ¼ oz. of gold or platinum, or of both together, to the ton of cast-iron; but for hard-castings he adds ½ oz. or more of the two metals, or of one of them. In puddling iron he introduces the gold or platinum just as the metal "comes to nature,"—*i. e.* by decarburization becomes malleable iron,—at the rate of about ¼ oz. to each ton of the pig or cast-iron used. In making puddled steel the nostrum is added in like manner. In making malleable iron or cast-steel by other processes

[a] A.D. 1861, Jan. 24, No. 196.

than by puddling, the nostrum is applied "at any stage of the process whilst the metal is still fluid;" and in making cast-steel it is melted "with the steel in crucibles or otherwise." The patentee is careful to acknowledge that it had been previously proposed to alloy gold or platinum with steel; and, in his opinion, "such efforts or experiments failed in producing any beneficial results," because the gold or platinum was used "in very large quantities," never smaller than several pounds to the ton of steel. This would be rather costly steel! The objection, however, does not apply to the alleged "improvements" of Longmaid, who may be fairly regarded as the Hahnemann of metallurgy. But before I become his disciple, I shall require something like evidence of the efficacy of his treatment. In the provisional specification of another patent,[3] Longmaid claimed the addition of aluminium or magnesium in small quantity during the operations of refining or puddling; but this claim was omitted in the specification itself.

According to Gueymard, certain varieties of cast-iron of Savoy are platiniferous.[4]

IRON AND RHODIUM.

Faraday and Stodart alloyed cast-steel with rhodium which was supplied to them for the purpose by Dr. Wollaston:[5] the metals unite in all proportions. Steel thus alloyed was characterized by remarkable hardness, combined with sufficient tenacity to prevent cracking either in forging or in hardening. In tempering cutting articles made of this alloy, it was necessary to heat them 16·6° C. (30° Fah.) higher than the best wootz, and wootz required to be heated full 22·2° C. (40° Fah.) above the best English cast-steel. The specific gravity of hammered steel containing 1·5 °/ₒ of rhodium was 7·795. Steel fused with its own weight of rhodium "gave a button, which, when polished, exhibited a surface of the most exquisite beauty." The colour of this alloy is described as the "finest imaginable" for metallic mirrors; it does not tarnish by long exposure to the atmosphere, and its specific gravity was 9·176.[6] The alloys of steel with rhodium were regarded by Faraday and Stodart as "perhaps the most valuable of all."

IRON AND PALLADIUM.

Faraday and Stodart fused 4 lbs. of steel with $\frac{1}{100}$ of palladium, and they describe the alloy as "truly valuable, more especially for making instruments that require perfect smoothness of edge."[7] I am not aware whether any other experiments have been made on this alloy. A few years ago the supply of palladium from South America was pretty abundant, and the selling price was between 1*l.* and 1*l.* 10*s.* per ounce; but of late it has become very scarce, and is now more than twice as costly as fine gold. To any one who may be disposed to

[3] A.D. 1861, No. 1863.

[4] Ann. de la Chambre Royale d'Agriculture et de Commerce de Savoie. Chambéry, 1858: p. 449. Quoted from the Report of the 24th Session of the "Congrès Scientifique de France."

[5] Quarterly Journ. ante cit. p. 329.

[6] Phil. Trans. ante cit. p. 256.

[7] Ibid. p. 254.

make further trial of this metal with reference to steel, a knowledge of the following facts will be useful. It cannot be melted in an ordinary blast-furnace, though it may by means of oxygen. According to Mr. Cock, who has had great experience in its preparation on the large scale, it is not oxidized in the air at the ordinary temperature, or at a bright redness; but it oxidizes in the air at dull redness, its surface becoming coloured in the same manner as iron or steel. By thus cautiously heating it for some time, it acquires a brittle coating of brown oxide, which, however, is reduced by a temperature very little beyond that required for its formation.[8]

Iron and Osmium-Iridium.

Faraday and Stodart fused pure iron with 3 % of osmium-iridium, and obtained a button, which when forged and polished was exposed with many other pieces of iron, steel, and alloys, to a moist atmosphere: it was the last of all showing rust. Its colour was distinctly blue; it hardened when heated to redness and quenched in water, and yet no carbon could be detected in it.[9]

Iron and Aluminium.

According to Deville, iron and aluminium directly combine in all proportions. He describes the alloys which contain from 7 % to 8 % of iron as hard, brittle, and crystallized in long needles. The alloy with 10 % of iron much resembles the tersulphide of antimony (SbS^3); by liquation this alloy yields a residue but little fusible, and aluminium less ferriferous.[1] Iron tools which are used in stirring molten aluminium become coated with a bright adherent layer of this metal. An alloy made by heating 10 parts by weight of aluminium with 5 of protochloride of iron under a mixture of 20 of the chlorides of potassium and sodium was crystalline; and by the action of very dilute hydrochloric acid yielded somewhat corroded six-sided prisms of the colour of iron. By long boiling with a solution of caustic soda, the whole of the aluminium is dissolved, and the iron left. It does not decompose water at 100° C., but it rusts in moist air. By analysis it was found to consist of 52·14 % of iron and 45·37 % of aluminium, so that it may be nearly represented by the formula $FeAl^2$, which gives 50·51 % of iron and 49·49 % of aluminium.[2] Messrs. Calvert and Johnson, of Manchester, have published the results of some experiments on the alloys of iron and aluminium.[3] "The first alloy of aluminium and iron was obtained by heating to a white-heat, for two hours, the following mixture:—

8 equivalents of chloride of aluminium	1076
40 equivalents of fine iron filings	1120·0
8 equivalents of lime	224·0

[8] Phil. Mag. 23. p. 18. 1843.

[9] Phil. Trans. ante cit. p. 268.

[1] De l'Aluminium, ses Propriétés, sa Fabrication, et ses Applications. Par M. H. Sainte-Claire Deville. Paris. 1859. p. 40.

[2] Ueber krystallisirte Verbindungen des Aluminiums mit Metallen. Inaugural-Dissertation. Ferd. Reinh. Michel. Göttingen. 1860. p. 33.

[3] Phil. Mag. Oct. 1855.

"The lime was added to the mixture with the view of removing the chlorine from the chloride of aluminium, so as to liberate the metal aluminium; by forming a fusible chloride of calcium, and subtracting the lime from the above proportions, we ought to have obtained an alloy having the composition of—

1 equivalent of aluminium	14	=	9·09
5 equivalents of iron	140	=	90·91
	154	=	100·00

whilst the alloy which we found at the bottom of the crucible was composed of 100 parts, as follows:—

Aluminium	12·00
Iron	88·00
	100·00

which leads to the following formula:—

1 equivalent of aluminium	11·11
4 equivalents of iron	88·89
	100·00"

The alloy, it is stated, "was extremely hard, and rusted when exposed to a damp atmosphere; still it could be forged and welded."

How the lime,—oxide of calcium,—could remove the chlorine from the chloride of aluminium, without at the same time oxidizing the aluminium, we are not informed.

By repeating the preceding experiment with the addition of some very fine charcoal powder, Messrs. Calvert and Johnson procured a similar alloy consisting of 87·91 % of aluminium and 12·09 % of iron. In the residual mass of chloride of calcium and charcoal were numerous globules varying in size from that of a large pea to that of a pin-head; they were extremely hard, and as white as silver, and did not rust in damp air, nor even when exposed to "hyponitric fumes;" they were composed of 24·55 % of aluminium and 75·45 % of iron, which corresponds to the formula $Al^2 Fe^3$. The authors state that "therefore this alloy has the same composition as alumina, the iron taking the place of the oxygen which exists in the latter." (!) By the action of weak sulphuric acid the iron was dissolved, leaving the aluminium in globules of exactly the same form as those of the original alloy. The authors promised further results, but I do not know whether that promise has been fulfilled.

Faraday and Stodart believed they had succeeded in obtaining an alloy of iron and aluminium by the direct reduction of alumina; and, as the subject may be of great practical importance, I present an account of their experiments *in extenso*. "Pure steel in small pieces, and in some instances good iron, being mixed with charcoal powder, were heated intensely for a long time; in this way they formed carburets, which possessed a very dark metallic grey colour, something in appearance like the black ore of tellurium, and highly crystalline. When broken, the facets of small buttons, not weighing more than 500 grains, were frequently above the eighth of an inch in width.

The results of several experiments on its composition, which appeared very uniform, gave 94·36 iron, +5·64 carbon. This being broken and rubbed to powder in a mortar, was mixed with pure alumine, and the whole intensely heated in a close crucible for a considerable time. On being removed from the furnace, and opened, an alloy was obtained of a white colour, a close granular texture, and very brittle: this, when analysed, gave 6·4 [=3·41 of aluminium] per cent. alumine and a portion of carbon not accurately estimated. 700 of good steel, with 40 of the alumine alloy, were fused together, and formed a very good button, perfectly malleable; this, on being forged into a little bar, and the surface polished, gave, on the application of dilute sulphuric acid, the beautiful damask . . . . belonging peculiarly to wootz. A second experiment was made with 500 grains of the same steel, and 67 of the alumine alloy, and this also proved good; it forged well, and gave the damask. This specimen has all the appreciable characters of the best Bombay wootz."[4]

Wootz had been previously analysed by Faraday,[5] and found to contain from 0·0128 % to 0·0695 % of aluminium; and, hence, it was inferred that the damask of this well-known variety of Indian steel was due to the presence of that metal. Karsten analysed genuine wootz, and was unable to discover in it appreciable traces of aluminium. He describes his method of analysis, which appears to be perfectly satisfactory. He is puzzled to understand how in Faraday's analysis the whole of the alumina should have been found in the residue insoluble in nitro-hydrochloric acid, especially as in his own experiments on the action of this acid on wootz only traces of silica were left undissolved.[6] The late Mr. T. H. Henry, who was an extremely accurate and trustworthy analyst, failed to detect the slightest trace of aluminium in wootz; and suggested that the aluminium found by Faraday might have been derived from intermingled slag containing silicate of alumina; for he remarked that in the wootz in little round cakes of the usual description, such as Faraday operated upon, "small particles of slag are often so intimately mixed with the metal as to defy separation." He preferred, consequently, to analyse a portion of a bar made from wootz, from which, during the process of forging, the slag might be expected to be more or less completely extruded.[7] But in the analysis of one specimen of wootz by Faraday alumina *without silica* was obtained.

Now, as Karsten remarks, there can be no doubt that Faraday in his analysis of wootz obtained a substance possessing the characteristic properties of alumina, however difficult it may be to account for the presence of the whole of that substance in the insoluble residue; and there can also be no doubt that the specimens of *genuine* wootz operated on by Karsten and Henry were free from aluminium. The conclusion, therefore, is that the quality of this steel does not, as Faraday and Stodart inferred, depend upon the presence of aluminium. But what

[4] Quarterly Journ. ante cit. p. 320.
[5] Ibid. 7. p. 288. 1819.
[6] 1. p. 484.
[7] Phil. Mag. 4. p. 42. 1852.

must be stated concerning the "alumine alloy" (in which the proportion of aluminium was ascertained by analysis), and the fact that the addition of this alloy to steel produced a metal in all respects resembling wootz? This, at least, is strong synthetical evidence, proceeding as it does from one of the most accurate and conscientious observers the world has yet seen.

In order that the reader may be able to form his own judgment concerning Faraday's results, I now subjoin in as condensed a form as possible the essential parts of his own description of the process so far as relates to alumina. The wootz was obtained from Sir Joseph Banks, and the piece operated on weighed 164·3 grs., and was cut from the middle of a cake when heated to cherry-redness, so that it was in the same state as it came from the crucible of the Indian steel-maker. It was heated in a flask with nitro-hydrochloric acid and gradually dissolved, with the separation of dark-coloured flakes, which were unalterable even in the boiling acid. When all action had ceased, the solution was poured off from the sediment, which was repeatedly washed with distilled water. During washing it became resolved into a black powder which sank to the bottom, and reddish brown flocculi which remained suspended, and which were found to be carbonaceous matter soluble in caustic potash. These were separated from each other and examined apart. The black powder was fused with potash in a silver capsule and the product treated with water, when a clear alkaline solution was obtained and a brown powder, which proved to consist chiefly of silver derived from the capsule. The solution was saturated with hydrochloric acid and evaporated to dryness, and the residue was re-dissolved in water with the addition of a little hydrochloric acid, when a very small quantity of white flocculi were left untouched, which were insoluble in acids, and had the characters of silica. The solution on the addition of carbonate of potash gave an abundant precipitate. This was washed, and when heated with a little solution of potash, dissolved in it like alumina. Sulphuric acid was then added, and a solution of alum was obtained, a little silica precipitating. In a second experiment, Faraday operated on 625 grs. of Indian steel in the same state as imported. "The appearance of it, whilst being acted upon by the acid, was very different to that of the wootz." It gave 0·024 % of alumina and no silica. Faraday also operated on 420 grs. of the best English steel, but "could obtain no earths from it." A slight appearance of opacity in a solution was at last produced, which he ascertained to be due to alumina derived from the tests employed. "Many comparative experiments," Faraday states, "were afterwards made with the three specimens of steel: those from India always appeared perfectly distinct from each other in the kind and quantity of earths they gave, and the English steel invariably appeared without the earths; neither was there the slightest reason offered for the supposition I at first entertained, that the earths came from the tests used in the analysis." [8]

[8] Quarterly Journ. 7. ante cit.

Karsten, in his analyses of various kinds of malleable iron, steel, and cast-iron, rarely detected aluminium, and then only in unweighable quantities. The method of analysis which he adopted is that usually described, namely, solution in nitro-hydrochloric acid, evaporation to dryness, moistening the residue with hydrochloric acid, dissolving in water, filtering, precipitating by ammonia, redissolving the precipitate in the smallest possible quantity of hydrochloric acid, then boiling with excess of potash, diluting with much water, filtering, acidifying the filtrate with hydrochloric acid, and finally adding excess of carbonate of ammonia.

Three experiments on a large scale were made by Karsten to ascertain the effect of adding alumina to the charge of cast-iron in the process of conversion into malleable iron in the charcoal hearth. The only result was to protract the process, owing to the formation of silicate of protoxide of iron in great quantity. There was no injurious effect upon the bar-iron, from which by analysis he scarcely obtained traces of alumina.[9] He doubted whether any reduction of alumina takes place in the blast-furnace; and concluded that aluminium would greatly diminish the tenacity of iron, as the bar-iron which yielded the strongest traces of alumina was always rotten.

The term damask, as applied to steel, is familiar to most persons; but as it may be unknown to some, I will now explain its meaning. It is used to designate the elaborate markings on the surface of certain varieties of polished steel, such as the renowned sword-blades of Damascus. Johnson's definition and derivation of damask are as follow: "Linen or silk woven in a manner invented at *Damascus*, by which part, by a various direction of the threads, exhibits flowers or other forms."[1] Now, if this be correct, it is a question whether the word damask as applied to steel may have been derived, not from the place of manufacture, but from the fancied resemblance between the markings in question and the damask patterns on textile fabrics. However, it seems most probable that the locality is really the origin of the name.

Iron and Chromium.

On this subject we are chiefly indebted to Berthier for information.[2] He states that iron and chromium may be alloyed in every kind of proportion; that the alloys are very hard, brittle, and crystalline in structure; and that they are "of a more grey and brighter white," less fusible, much less magnetic, and much less easily attacked by acids than iron. The degree in which these properties are manifested is proportionate to the amount of chromium in the alloy. The alloy containing 17°/₀ of chromium, *i.e.* nearly of the formula Fe^5Cr, is described by Berthier as almost silver white, fibrous in structure, with difficulty attacked by acids, and very brittle. The alloy containing 60°/₀ of chromium was melted into a well-rounded button, which was

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[9] I. p. 483.

[1] A Dictionary of the English Language. 1805. Longman and Co.

[2] Tr. 2. p. 214.

full of large bubbles, lined with elongated and intersecting prismatic crystals; it is whiter than platinum, and so fragile that it may be reduced to fine powder in an agate mortar; its hardness is so great that it scratches glass almost as deeply as a diamond; it is attacked with great difficulty by the strongest acids, even the nitro-hydrochloric. Berthier states that these alloys may be easily obtained by very strongly heating in brasqued crucibles the mixed oxides of iron and chromium; and when the oxide of chromium predominates, the addition of a little charcoal powder is desirable in order to promote reduction. When the quantity operated on is considerable, sufficient charcoal powder to effect reduction should be intermixed. They may also be prepared from chrome-iron ores; but in that case a flux is required to retain the silica and alumina which may be present in these ores. A good flux for this purpose is a mixture of 100 parts of glass (free from lead) and 40 of glass of borax to 100 of ore. According to Fremy an alloy of iron and chromium may be formed by heating in a blast-furnace oxide of chromium and metallic iron; it frequently crystallizes in long needles; it resembles cast-iron, and scratches the hardest bodies, even hardened steel.[3] Like chromium, the alloys of this metal and iron are stated to resist the action of concentrated acids.

The following experiments have been made by Mr. Smith in my laboratory:—Red hæmatite nearly pure was used, and sesquioxide of chromium prepared by heating together chloride of ammonium and bichromate of potash, washing out with hot water, and igniting. The quantities weighed out were intimately mixed, and put into a charcoal-lined French crucible; the cavity afterwards filled up with charcoal powder; the whole luted over, and exposed to a white heat for 2 hours.

Proportions taken for the experiments as follow:—

	I. Grains.	II. Grains.	III. Grains.	IV. Grains.
Hæmatite	190	150	150	50
Sesquioxide of chromium	10	50	150	150
Carbon	*50	*50	†75	†50
Weight of metal obtained	152	145	229	147

* Charcoal powder. † Anthracite powder.

Percentage composition of metal obtained:—

Iron	‡95·76	72·93	45·37	23·42
Chromium	4·24	‡27·07	‡54·63	‡76·58

‡ Carbon present; amount not determined.

If we suppose the hæmatite contains 70°/$_0$ of iron, and the sesquioxide of chromium 69°/$_0$ of chromium, and the whole of the metals be separated without taking up carbon, the buttons of metal should have weighed 137·9, 139·5, 208·5, and 138·5 grs. respectively, and con-

[3] Comptes Rendus, 44. p. 632. 1857.

tained 95%, 75·2%, 50·3%, and 25·3% of iron; thus approximating to the formulæ $Fe^{12}Cr$, $Fe^{3}Cr$, $FeCr$, $FeCr^{3}$.

Ex. 1. Result. A well-fused button with globules; attracted by the magnet, with traces of interlacing crystals on the external surface; hard, splits under the hammer, and scratches glass; fracture white and bright, with crystalline plates extending across the fractured surface. Digested with dilute sulphuric or hydrochloric acid, it evolves fetid hydrogen, and leaves traces of black residue. The chromium only was determined.

Ex. 2. Result. A well-fused button with globules; attracted by the magnet; hard, and scratches glass; brittle; readily reduced to powder; fracture tin-white, very bright, and finely granular; crystalline. On boiling the finely powdered metal with sulphuric and hydrochloric acids, it is acted on with difficulty. Fetid hydrogen is given off, a scum forms on the surface of the solution, and a residue is left which resists the prolonged action of the acid. This residue was decomposed by repeated fusions with a mixture of lime and nitre. Of the total amount of iron present, this residual metal contained 1·71%, and in another determination 6·34%. Iron only was determined in the alloy.

Ex. 3. Result. A somewhat spongy button with metallic globules; not attracted by the magnet; hard; scratches glass; easily crushed and reduced to powder; fracture finely granular, bright, and greyish-white. Action of acids on the alloy similar to 2. Of the total amount of iron present, the residue contained 5·37%; in another estimation, 7·69%. Iron only was determined.

Ex. 4. Result. An imperfectly fused spongy mass, less coherent than 3. Not attracted by the magnet; very hard; scratches glass; can be crushed and reduced to powder; colour yellowish-grey white; lustre somewhat dull. Centre portion of button filled with minute needle shaped crystals, which have a bright reflecting surface. Action of acids on the alloy similar to 2. Of the total amount of iron present, the residue contained 6·95%; in another experiment, 0·61%. Iron only was determined.

With regard to steel, Berthier found that the addition of 1% or 2% of chromium to the molten metal communicates hardness and the property of taking a very beautiful damask, without diminishing its malleability. Faraday and Stodart have examined the effect of chromium on steel, and obtained the following results:—[4]

1. A mixture of 1600 grs. of steel and 16 grs. of pure chromium was fused, and kept so for some time. The button was good, and, though hard, forged well, without showing any tendency to crack. The alloy should have contained 0·99% of chromium. The surface, after having been brightened and slightly acted upon by dilute sulphuric acid, appeared crystalline; and by similar treatment of the

[4] Phil. Trans. ante cit. p. 267.

forged metal a "very beautiful damask" was produced, which was ascribed to the elongation of the crystals by the process of forging.

2. A mixture of 1600 grs. of steel and 48 grs. of pure chromium was melted as before. The button should have contained 2·91% of chromium. It was considerably harder than the last, was as malleable as pure iron, and also gave a very fine damask. "The damask was removed by polishing, and restored by heat without the use of any acid. The damasked surface, now coloured by oxidation, had a very novel appearance: the beauty was heightened by heating the metal in a way to exhibit all the colours caused by oxidation, from pale straw to blue, or from about 463° to 600° Fah. (from about 239° C. to 315° C.)"

Mushet has obtained a patent for "adding to and melting with any mixture of materials which when melted produces cast-steel, a quantity of a mixture of pulverized pig-iron, cast-iron, or refined iron and oxide of manganese with pulverized chrome ore or oxide of chromium," with or without the addition of "pulverized wolfram ore, or tungstic acid."[5]

I have not met with any trustworthy observations or experiments on the action of chromium upon cast-iron. Karsten examined bar-iron made from cast-iron containing a small quantity of chromium, but failed to detect a trace of this metal; from which it appears that in the process of converting cast into malleable iron in the charcoal hearth, the whole of the chromium is separated.

Iron and Tungsten.

Tungsten was first obtained in the metallic state by the brothers D'Elhuyar, Spaniards, in 1783. They communicated their researches to the Academy of Sciences at Toulouse, March 24th, 1784, in an admirable memoir, which is well worthy of perusal even at the present day.[6] They attempted to prepare alloys of tungsten by heating the acid (WO^3) and the metals in brasqued crucibles. They described its alloys of gold, platinum, copper, lead, tin, antimony, bismuth, zinc, manganese, and white cast-iron, but not with malleable iron or steel. All that they state with regard to iron is that, "with the iron of white cast-iron it formed a perfect button, of which the fracture was compact and greyish-white. It was hard, tender (*aigre*), and weighed 137 grs." They prepared it by reducing tungstic acid with carbon at a high temperature. M. Riche is the only person who has succeeded in fusing tungsten, and he did so by means of a current from a battery of 200 ordinary Bunsen-cells belonging to the Faculty of Sciences, Paris. Under the conditions a considerable portion of the

[5] A.D. 1861, July 19, No. 1817. Improvements in the Manufacture of Cast-steel.

[6] Mémoire sur la nature du Volfram et celle d'un nouveau métal qui entre dans sa composition. Par MM. D'Elhuyar frères, correspondants. Lu le 24 Mars, 1784. Histoire et Mémoires de l'Académie Royale des Sciences, Inscriptions, et Belles Lettres de Toulouse. 1784. 2. p. 141.

metal oxidizes with the production of a greenish-blue flame. Riche states that it also fuses and very quickly before the oxy-hydrogen blowpipe; but then the greater part of the metal oxidizes and is dissipated in fumes of tungstic acid. According to the same observer, tungsten reduced from tungstic acid by hydrogen is in distinct bright crystalline grains, which take a fine polish on friction and scratch glass with facility.[7] I may state that many years ago I devoted considerable time to an experimental investigation respecting certain compounds and alloys of tungsten, of which the results will hereafter be duly recorded. I could not melt the metal at the highest temperatures of air-furnaces, or of Sefström's blast-furnace. By reducing crystallized tungstate of ammonia in a current of hydrogen at a red-heat, I obtained the metal in the form of the crystals with a bright metallic lustre and tin-white colour. Whether nitrogen is concerned in this result, I do not know. Aikin and Allen long previously published the fact that by the reduction of acicular crystals of tungstate of ammonia they procured the metal in roundish grains "about the size of a pin's head, with a very brilliant metallic lustre."[8]

The alloy composed of 63 °/₀ of iron and 37 °/₀, *i.e.* nearly according to the formula Fe^6W, is described by Berthier as having a whiter grey colour than iron, brilliant, hard, more brittle than common cast-iron, and lamellar in structure; it was somewhat bubbly.[9] The following observations on the triple alloy of iron, manganese, and tungsten are also by Berthier. The well-known mineral wolfram, after having been very strongly heated in a brasqued crucible, gave an alloy consisting of 16·4 °/₀ of iron, 5·8 °/₀ of manganese, and 77·8 °/₀ of tungsten, *i.e.* nearly corresponding to the formula Fe^3MnW^4. It requires the highest temperature of furnaces for fusion; it is hard, brittle, and lamellar, and resembles white cast-iron. With 14 parts by weight of wolfram and 9·5 parts of iron scales, Berthier got an alloy consisting of 43·4 °/₀ of iron, 3·5 °/₀ of manganese, and 53·1 °/₀ of tungsten, *i.e.* nearly corresponding to the formula $Fe^{13}MnW^4$. It was hard, brittle, lamellar, platinum-grey in colour, and completely fusible.

In 1844 the Duc de Luynes published a memoir on the manufacture of cast and damasked steel.[1] In nine analyses which he has given of various kinds of Oriental damasked steel, tungsten appears in eight; in six of these, it is stated, only traces of that metal were present; while of the other two, one contained 0·518 °/₀ and the other exactly 1 °/₀ of it. In all of these analyses nickel appears as a constituent, ranging from "traces" to 3·9355 °/₀, and the proportion of carbon set down so far exceeds that which has been found even in the most highly carburized cast-iron by trustworthy observers,—the

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[7] Thèse présentée à la Faculté des Sciences de Paris. Par M. Alfred Riche. 1857. p. 13.

[8] A Dictionary of Chemistry and Mineralogy. By A. and C. R. Aikin. 1807. 2. p. 445.

[9] Tr. 2. p. 215.

[1] Mémoire sur la fabrication de l'acier fondu et damassé. Par H. de Luynes, Paris. 1844. I have not seen the original, but quote from the notice in Dingler's "Polytechnisches Journal," 96. p. 106. 1845.

smallest proportion being 7·758 % and the largest 13 %,—that the competency of the Duke as an analyst may fairly be questioned. I shall, therefore, dismiss from further consideration the analytical statements of the author of the memoir in question, and the conclusions which he may have drawn from them. However, he made several synthetical experiments, of which a record may be interesting.

1. A mixture of 2000 parts by weight of soft nail iron, 100 of wolfram, and 175 of oak sawdust, was heated to bright redness in a brasqued crucible; the product, which was well fused, was remelted with an equal weight of nail iron, when a very malleable steel with a beautiful damask was obtained.

2. A mixture of 3000 of nail iron, 144 of carbonate of protoxide of manganese, 150 of wolfram, and 270 of sawdust, was treated in exactly the same manner, and gave the same result.

3. A mixture of 1000 of nail iron, 48 of carbonate of protoxide of manganese, 10 of tungstic acid, 10 of oxide of nickel, and 113 of sawdust, gave a beautiful result, but the steel was more difficult to work than that made with wolfram; yet it took a good damask. There was no improvement when the nickel and manganese were omitted.

4. A mixture of 2000 of nail iron, 100 of peroxide of manganese, and 275 of sawdust, gave a very beautiful steel with a good damask.

5. A mixture of 1000 of nail iron, 96 of carbonate of protoxide of manganese, 20 of tungstic acid, and 128 of sawdust, gave a tolerably unsound and porous mass of steel, which, however, could be worked very well and took a beautiful damask.

Other experiments with compounds of manganese were made, which, together with those above recorded, led the author to conclude that the damask depended entirely on the presence of manganese,—a conclusion which, it need hardly be observed, few will adopt. The author makes the very startling statement that by the reduction of crystallized pyrolusite in a brasqued crucible, manganese was produced which contained 23 % of carbon and 2 % of nickel!

The alloys of iron and tungsten have been investigated by Bernouilli, and his experiments were made at the Royal Iron Foundry, Berlin.[a] He did not succeed in melting tungsten at the highest temperatures which he could command, and which sufficed to fuse Hessian crucibles; but obtained only a sintered mass, having a bright metallic lustre. In one instance the metal was heated in a porcelain furnace during 18 hours, yet without melting. The specific gravity of tungsten reduced from tungstic acid by carbon ranged from 17·1 to 17·3, and that reduced by hydrogen from 17·9 to 18·2. Intimate mixtures of English grey graphitic cast-iron turnings and 1, 2, 3, 4, 5, 10, 15, 20, 30, 40, and 50 per cent. of pure tungstic acid were exposed to an intense white heat in graphite crucibles, and when the proportion of acid exceeded 20 % a thin layer of charcoal powder was put at the bottom of the crucible and on the top of the mixture.

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[a] Ueber Wolfram und einige seiner Verbindungen; von Dr. F. A. Bernouilli. Ann. d. Phys. u. Chem. Poggendorff. 21. p. 573. 1860.

Under that proportion it was considered that the carbon in the cast-iron would suffice to reduce the tungstic acid. With 75 % it required exposure to the intensest white heat during 1½ hour to produce a melted button; and with 80 % by exposure to the same temperature during 3 hours, only an irregular porous mass was obtained, of which the fracture was conchoidal and of a beautiful silver-white colour: it was so hard as without very sharp edges easily to scratch glass and quartz. With from 1 % to 3 % there is little apparent change in the iron, but it is slightly more perceptible with 4 % and 5 %. With 10 % the iron acquires steel-like properties, it gives a very clear sound, is light grey, and extremely fine grained in fracture, and is somewhat malleable. With 15% it may almost be designated pure steel, though not so malleable as to admit of being applied; it is very hard; a thin rectangular cast-bar of this alloy was pretty easily forged with a cold chisel, which, after being hardened like ordinary steel, cut cast and wrought-iron with ease without becoming blunted. With 20 % the alloy has similar properties, but is harder and less malleable. Beyond 20 % the deterioration in these respects increases, and with 50 % the alloy can no longer be hammered out. If the cast-iron was employed in larger compact pieces, even with 30 % of tungstic acid, the alloy was white, very hard and brittle, yet was a little malleable after annealing. When charcoal (*i.e.* smelted with charcoal) grey cast-iron was substituted for coke cast-iron,—the material used in the foregoing experiments,—precisely the same results were obtained, except that in consequence of the greater purity of the former the product was of better quality. On the contrary, the results were quite different with *white cast-iron*, whether spiegeleisen or common white-iron. A similar series of experiments was made of melting white cast-iron with tungstic acid, but no alloy of tungsten was produced, except when charcoal powder was added; without this addition nearly the whole of the acid is slagged off, and only a very small quantity of the metal passes into the iron. The alloys produced with the addition of charcoal, of which it was found most convenient to put some at the bottom of the crucible and to strew some upon the iron, are homogeneous like those made with grey cast-iron, though never steel-like in appearance, but white in fracture, of the same structure as the iron employed, and not in a sensible degree malleable. Experiments were also made with metallic tungsten, wolfram, and scheelite (CaO, WO^3), and the results were essentially the same, except that the manganese in wolfram was not without influence. Bernouilli arrived at the following conclusions: —Only the graphitic or mechanically mixed carbon in cast-iron can reduce tungstic acid, and the combined carbon has no such effect. Hence, by melting turnings of grey cast-iron with a suitable proportion of tungstic acid, cast steel may be directly formed. When grey cast-iron in pieces is used, steel is not produced, because the iron melts, and the intimate contact requisite between it and the acid to cause the removal of the proper amount of carbon is thereby prevented. It was ascertained that when more tungstic acid was added than sufficed to burn out the whole of the carbon, yet the alloy by the

action of acids evolved an odour of hydro-carbon. Bernouilli has given the following tabular statement of his results.

Kind of cast-iron used.	Percentage of tungstic acid added.	Carbon contained in the Iron. Mechanically mixed.	Chemically combined.	Total.	Percentage of carbon in the alloy.	Physical properties of the alloys.
Grey cast-iron...	0	3·19	0·92	4·11	...	
	5	...	...	...	1·02	Grey in fracture, not malleable.
	15	...	...	...	0·93	Steel.
	25	...	...	...	0·91	
	60	...	...	...	0·94	Grey, very hard and strong, not malleable.
Spiegeleisen....	0	...	5·19	5·19	...	
	5	...	...	...	5·18	White, very hard and brittle.
	15	...	...	...	5·09	
	25	...	...	...	4·92	
	60	...	...	...	4·93	
Ordinary white cast-iron......	0	...	3·91	3·91	...	
	5	...	...	...	3·70	
	15	...	...	...	3·81	White, very hard and brittle.
	60	...	...	...	3·75	

In 1857 Mr. Robert Oxland, of Plymouth, obtained a patent for "Improvements in the manufacture of alloys or compounds containing tungsten," and the following are some of the claims in the specification.[3] The metal reduced from wolfram by carbon "may be mixed with iron in the blast-furnace, or melted with pig-iron in a cupola. About 30 per cent. of the metal may be so mixed with iron. The alloy of cast-iron with tungsten may be used for metallurgical purposes, or for making blue oxide of tungsten and tungstic acid. . . . Good cast-steel is obtained by melting ½ to 25 per cent. of wolfram metal with the steel. . . . Alloys of iron and wolfram metal may be refined and made into cast-steel by cementation in the usual way. Refined wolfram cast-iron has its crystallization destroyed by being hammered cold." The same specification also includes a claim for alloying tungsten with German silver and nickel; and if this be not a distinct invention of itself, I know not what is. But in 1848 I communicated to the British Association at Swansea the results of experiments on the alloys of tungsten with various metals, and amongst these German silver and nickel are specially mentioned.[4] I found these alloys, if such they can be designated, to be worthless; but supposing it had been otherwise, I presume that the communication to the British

[3] Extracted from the Abridgments of the Specifications relating to Metals and Alloys. 1861, p. 357. A.D. 1857, Dec. 18, No. 3114.

[4] British Association Report for 1848, p. 57.

Association nine years previously to the date of Mr. Oxland's patent would be regarded as publication, even in the eye of the present unjust patent law.

The application of tungsten to cast-steel soon attracted attention, especially in Austria; and to Mayer, of Leoben, Styria, is assigned the merit of having first carried it out on the large scale.[5] Tungsten, or wolfram steel, was announced as an important invention; in fineness of grain, uniformity of structure, hardness, toughness, strength, and durability it was declared superlative. It was specially adapted for various kinds of tools, such as chisels, cutting and boring instruments, etc.; and although it was somewhat more expensive than steel previously employed for such objects, yet it lasted four times as long and cost less than English cast-steel. At the congress of miners and smelters in Vienna in 1858 wolfram steel was exhibited in various forms. There were swords of it, which were regarded as perfection, so far as the quality of the metal was concerned: they were sharp, hard, tough, and elastic. My colleague, Mr. W. Smyth, attended this congress, and brought back for me specimens of this steel, of which the fracture is remarkably fine, uniform, compact, and conchoidal. I sent specimens of it to my friend, Mr. E. F. Sanderson, the well-known steel-maker of Sheffield, and the report which he communicated to me as to its working and other qualities was by no means favourable. In the International Exhibition of 1862, wolfram steel was not absent from the Austrian department; but there was no display of it, properly so called, as there undoubtedly would have been if a fraction of the predictions uttered as to its value had been fulfilled. I particularly sought information from Professor Tunner, of Leoben, concerning this steel, and his only reply was a significant shake of the head, which was more expressive even than words. No man can have had a better opportunity of knowing the truth in this matter than Professor Tunner, and there is no man to whose judgment upon it I should attach greater weight. Wagner's recent report is confirmatory of this opinion. He considers that the augury is unfavourable respecting the "wolfram steel industry;" and he states that files, razors, etc., are sold as wolfram steel, although they do not contain a trace of tungsten.[6] The strenuous efforts which have been made to force this steel into use, and the highly laudatory notices of it which from time to time have appeared, will not avail against the substantial truth of experience. Should the verdict be ultimately against this steel, it will teach us a lesson of caution, even with regard to opinions from practical establishments. We are informed that the conclusion to be drawn from the trial of tungsten steel in the workshops of Egels, and of Schwarzkopff and Freund of Berlin, at the Bochum Steel-works in Westphalia and elsewhere, is, that "*tungsten steel furnishes much more advantageous results than the best cast-steel employed up to the present time in commerce*" (sic in italics.)[7]

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[5] Berg. u. hüttenm. Zeit. 18. p. 275. 1859.

[6] Jahresbericht, 1860, p. 85.

[7] Revue Universelle des Mines, etc., March, 1860, p. 88. A full account of the history and manufacture of tungsten-steel, by M. A. Delvaux de Fenffe, appears in this number.

The tenacity or tensile strength of tungsten steel appears to be very considerable. The following results on this point were obtained at the Imperial Polytechnic Institution of Vienna :[8]—

Quality of steel.	Minimum sectional area in square millimetres.	Weight required to determine rupture.	Absolute tenacity.
Tungsten steel...............	41·64	4256	102 2
id.	40·25	4340	107·8
id.	43·03	5040	117·1 { rupture did not occur at the minimum section.
English steel, Huntsman...	38·17	3220	84·4
	43·03	3727	86·6
Reichraming steel...........	43·03	4838	112·4
	44·41	4676	105·3
	45·58	4200	92·1

Siewert has published the following results of samples of tungsten steel prepared in Vienna and at the Bochum Steel-works :[9]—

	1.	2.	3.	4.	5.	6.
Iron	—	—	95·85	—	96·37	—
Tungsten	1·05	2·84	3·05	—	2·71	—
Manganese........	—	—	traces	—	traces	—
Carbon	—	—	—	1·04	—	1·03

No. 1 was from Vienna, and the rest from the Bochum Works. Silicon was not detected with certainty in any.

The following directions for the preparation and use of tungsten have been published. Wolfram is gently roasted, then treated with dilute acids, and afterwards washed with water. Arsenic and sulphur are by this treatment removed. The dry residue is strongly heated during 24 hours in brasqued crucibles, whereby, it is alleged, carbides of iron and manganese are formed, and the tungstic acid is reduced to the metallic state. A slightly sintered mass is obtained, having a dark colour and a high specific gravity. From ½ % to 25 % of this is added to the steel previously to melting.[1]

Mr. Robert Mushet has patented the use of tungsten in one form or other in connexion with the manufacture of cast-steel.[2] Tungsten, tungstic acid, or oxides or ores of tungsten, are all appropriated by this gentleman ; but wolfram is preferred, because it costs less and contains manganese, which facilitates fusion. The wolfram is directed to be well pulverized, and when it contains 70 % or 75 % of tungstic acid, or 60 % of tungsten, it is to be mixed with an equal weight of melted pitch, and poured upon a slab of stone previously wetted. The fol-

[8] Revue, ut supra.

[9] Jahresbericht (continuation of Liebig and Kopp's), 1860, p. 690.

[1] Berg. u. hüttenm. Zeit. 19. p. 27. 1860.

[2] Vide Abridgments of Specifications relating to Metals and Alloys, 1861, p. 407. The title of the patent is, "An improvement or improvements in the manufacture of cast-steel." A.D. 1859 : January 12, No. 101 ; Feb. 24. No. 500 and No. 501 ; March 18, No. 690 and No. 691. A.D. 1861 : July 19, No. 1817.

lowing proportions are recommended to be melted in an ordinary crucible, and cast into ingots:—

Blister-steel 46 lbs., wolfram and pitch 1 lb. Or, Swedish bar-iron 44 lbs., charcoal in nubs 8 ozs., wolfram and pitch 1 to 4 lbs., puddled steel 48 lbs., charcoal in nubs 2½ ozs., wolfram and pitch 1 lb. The iron or steel is reduced to small pieces. The hardness of the alloy may be increased by using larger proportions of carbonaceous matters or smaller proportions of tungsten.

Whether Mr. Mushet has any equitable claim to appropriate to his own exclusive benefit the use of tungsten in connexion with the manufacture of iron or steel, may appear doubtful after the preceding history of the subject. Patent-law may give a legal claim, but legal claims are sometimes far from being founded on justice.

Iron and Molybdenum.

According to Berthier the compounds of molybdenum and iron are perfectly analogous to those of iron and tungsten. He describes an alloy of iron with 2·0% of molybdenum as fusible, whiter than iron, extremely hard, brittle but tenacious, and uneven and granular in fracture.[3] Berzelius states that an alloy of equal parts by weight of iron and molybdenum is hard, brittle, of a bluish gray colour, fusible before the blowpipe, and granular in fracture; and further that an alloy of 1 part by weight of iron and 2 of molybdenum is tender, bright grey, infusible before the blowpipe, attractable by the magnet, and finely granular in fracture.[4] In the First Part of 'Metallurgy,' under the head of Copper, I have described certain remarkable ferriferous "bears," containing a large amount of molybdenum.

Iron and Vanadium.

Vanadium was discovered by Sefström in his examination of the well-known iron of Taberg, which, according to Berzelius, is the softest of all the varieties of Swedish iron.[5] By the solution of several pounds of this iron he obtained scarcely 1½ grain of vanadium; but in the slags from the charcoal-hearth in which it was made, he found it in much larger quantity. I am not aware whether any investigation has been made concerning the effect of this metal upon iron, steel, or cast-iron.

Iron and Tantalum.

Berzelius asserts that iron alloys easily with tantalum, when tantalic acid is heated with iron filings in a brasqued crucible. The alloy is hard enough to scratch glass. It has not the least ductility, yet it is very difficult to break; the colour of its powder is dark brown. Acids partially dissolve it, leaving metallic tantalum in the state of powder.[6]

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[3] Tr. des Ess. 2. p. 215.
[4] Tr. 2. p. 706.
[5] Berzelius, Jahresber., 11. p. 97. 1832.
[6] Tr. 2. p. 707.

Iron and Potassium.

Gay-Lussac and Thenard discovered an alloy of iron and potassium, in making potassium in an iron tube according to their well-known process. It was formed by the long exposure of iron turnings at a high temperature to the vapour of potassium. Iron thus alloyed was described as very flexible, and occasionally so soft as to admit of being easily cut with scissars, and even scratched by the finger-nail; it oxidized in the air, decomposed water with lively effervescence, and soon acquired its original properties.[7]

Calvert and Johnson state they have alloyed potassium with iron by exposing to a very high temperature a mixture of fine iron-filings and bitartrate of potash. A mixture of 336 grs. of iron and 1504 of the bitartrate, *i. e.* in the ratio of 3 equivalents of iron to 2 of potassium, yielded a large button composed of 74·60% of iron and 25·40% of potassium, *i. e.* of the formula Fe^4K. The alloy exactly resembled malleable iron in appearance, and could be forged and welded; yet, strange to say, it was so hard that at ordinary temperatures it was scarcely indented by a heavy sledge-hammer, and was barely affected by the file! The iron of the alloy, notwithstanding its association with so large an amount of potassium, oxidized rapidly under water and in the atmosphere. In another experiment with the same proportions of iron and bitartrate of potash, but with the addition of some finely pulverized charcoal, an alloy was produced consisting of 81·42% of iron and 18·58% of potassium, *i. e.* of the formula Fe^6K. There was a thin layer of cast-iron on the surface of the button; but in other respects it was exactly similar to the last. When carbonate of potash was substituted for bitartrate "no results were obtained." These alloys seem to have been surprisingly definite in atomic constitution.[8]

Iron and Glucinium.

According to Stromeyer an alloy of these metals may be easily obtained by intensely heating a mixture of glucina, iron-filings, and lamp-black. It is described as whiter and less ductile than iron.[9] Davy obtained the alloy by heating to whiteness glucina in admixture with iron and potassium; and also by decomposing slightly moistened glucina in an atmosphere of hydrogen by a powerful voltaic current, using as the negative pole an iron wire which melted and became alloyed with glucinium.[1]

Iron and Barium.

Gay-Lussac and Thenard attempted to reduce baryta by exposing it to a very high temperature in a blast-furnace in admixture with iron, without as well as with the addition of charcoal; but there was no sign of reduction.[2]

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[7] Recherches Physico-Chimiques, 1. p. 238. 1811.

[8] Phil Mag. Oct. 1855.

Berzelius, Tr. 2. p. 704. Gmelin, Hand. 5. p. 275.

[1] Gmelin, Hand. 5. p. 274.

[2] Recherches Physico-Chimiques, 1. p. 106.

Iron and Strontium.

Gay-Lussac and Thenard endeavoured to reduce strontia in the same manner as baryta, and the result was equally negative.[3]

Iron and Calcium.

Gay-Lussac and Thenard obtained no evidence of the separation of calcium by exposing a mixture of iron and lime in an excellent crucible to the highest temperature of a blast-furnace, either with or without the addition of carbon.[4] Berzelius failed to produce any decided alloy of iron and calcium by strongly heating a mixture of iron-filings, lime, and charcoal powder.[5] Karsten found 0·1774 % of calcium in iron, which was deficient in weldability and tenacity, though neither red- nor cold-short. This iron resulted from the addition of carbonate of lime in large quantity during the entire operation of converting a charge of cast-iron into malleable iron in the charcoal-hearth.[6] I have heard it maintained by managers of forges that when limestone is used as a lining in puddling-furnaces the iron produced is apt to be red-short. Calcium in small quantity will be found in many published analyses of cast-iron. It will be perceived that our knowledge of the direct action of this metal upon iron, whether malleable iron, steel, or cast-iron, is extremely limited and unsatisfactory.

Iron and Magnesium.

By heating a mixture of magnesia, iron-filings, and charcoal in powder, Berzelius obtained indications of an alloy of iron and magnesium.[7] Karsten never detected a trace of magnesium in any wrought-iron which he examined; and, so far as I am aware, there is not any trustworthy information concerning its effect upon malleable iron. It occasionally appears as a constituent in minute proportion in the published analyses of cast-iron.

ORES OF IRON.

The ores of iron, properly so called, always contain the metal in the oxidized state. They consist of magnetic oxide, sesquioxide, hydrated sesquioxide, and carbonate of protoxide in various degrees of purity. They are widely and profusely distributed over the surface of the earth, and occur, one or more of them, in nearly every geological formation in veins, masses, or beds. To describe the localities of the iron ores of the world would require a large volume; and it is not, therefore, proposed to present any such description, even in a compendious form, in this work. In a treatise on the metallurgy of iron, the chief considerations with respect to the ores of iron are their composition, and the influence of various matters which they may contain

[3] Op. cit. 1. p. 107.
[4] Recherches Physico-Chimiques, 1. p. 107.
[5] Tr. 2. p. 704.
[6] 1. p. 487.
[7] Tr. 2. p. 705.

upon the quality of the metal reduced from them; and to these points attention will be specially and mainly directed. An exception, however, will be made in the case of British iron ores, and certain foreign ores of particular interest; and these will be treated in much detail.

Magnetic oxide of iron, magnetite. Fe^3O^4, *or* FeO,Fe^2O^3.—When pure it contains 72·41 % of iron. It occurs crystallized, massive, and in the state of sand, more or less distinctly crystalline. Chrome iron ore is sometimes met with in a similar state in minute octahedral crystals, and may readily be mistaken for magnetic iron sand; but it may be instantly distinguished from the latter by being non-magnetic. It is one of the most important of the ores of iron, and is that from which the finest qualities of steel have always hitherto been produced. It is widely diffused over the globe, and occurs in the so-called igneous and metamorphic rocks. It is found abundantly at Gellivara in Lapland, in Norway, at Dannemora, Taberg, and other localities in Sweden, in Canada, and in New Jersey, Pennsylvania, and elsewhere in the United States.

In the last International Exhibition, 1862, specimens of the magnetic iron ore in the Canadian collection attracted much attention.[8]

Franklinite.—The formula of this mineral is still doubtful. It was

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[8] The following information on this subject is given on the authority of Sir William Logan, Director of the Geological Survey of Canada.[*] The mine, commonly known as the *Big iron ore bed of Marmora*, Belmont, appears to consist of a succession of beds, one measuring 100 ft. in thickness. The total breadth of the mass is 528 ft. It belongs to the Laurentian series, lies between beds of gneiss and crystalline limestone, and is interstratified with thin bands of crystalline limestone and talcose slate, associated with diallage rock, serpentine, and epidosite. "The ore contains between 60 % and 70 % of iron. Many years ago a furnace was erected at Marmora to smelt it, and iron of superior quality was manufactured. More recently different companies have for short periods renewed smelting operations, with very satisfactory results in respect to the quality of the iron produced; but the distance of the place from a shipping port has proved a serious obstacle to success. At present (1862) the furnace is not in blast." At Newborough, S. Crosby, there is a bed 200 ft. thick in gneiss, also in the Laurentian series. It is situated on Mud Lake, a part of the Rideau Canal. The ore is supplied at Kingston, for 2¼ dollars the ton, to vessels which carry it as back freight to Cleveland on Lake Erie; whence it finds its way to the smelting furnaces at Pittsburg on the Ohio, in Pennsylvania. About 4000 tons of the ore were thus exported in 185?. There is a third bed about 90 ft. thick at Hull. It is surrounded by gneiss, and appears to present the form of a dome, through the summit of which an underlying mass of limestone protrudes. It is in the Laurentian series. The ore contains between 60 % and 70 % of iron, and in some parts of the bed it is mingled with a little graphite. It began to be worked in 1854, and was smelted at Pittsburg, whither it was sent by way of Kingston, on Lake Ontario, to which it was conveyed by the Rideau Canal. Up to 1858 about 8000 tons of the ore had been thus exported, but the opening of the Newborough Mine, more favourably situated in regard to the shipping port, stopped the working, and no ore is now (1862) exported from Hull. At Madoc is a fourth bed 25 ft. thick in gneiss in the Laurentian series. The ore is stated to contain about 70 % of iron, and to be very free from sulphur. Disseminated through it are nodules of radiating crystals of *actinolite*, and yellow *uranite* has been found lining small cracks. It is strongly polar. It was formerly smelted, and produced iron of very fine quality, but the furnace is not now in blast (1862). Other smaller beds are also described.

[*] Descriptive Catalogue of a Collection of the Economic Minerals of Canada, etc., sent to the London International Exhibition for 1862. Montreal.

regarded as consisting essentially of magnetic oxide of iron, with the protoxide of iron partially replaced by oxide of zinc; but, if the following analysis of Rammelsberg be correct, this view cannot be admitted.[9]

Sesquioxide of iron	64·51	=	Iron	45·16
Binoxide of manganese (MnO^2)	13·51		Manganese	9·38
Oxide of zinc	25·30		Zinc	20·30
	103·32		(Oxygen	25·16)
				100·00

The presence of protoxide of iron may be inferred from the excess on analysis. According to Rammelsberg, it probably consists of $4Mn^2O^3$, $8Fe^2O^3$, 21FeO, and 15ZnO, and its composition may be expressed by the formula $3(FeO, ZnO,)+(Fe^2O^3, Mn^2O^3)$. Franklinite occurs in New Jersey, U.S., and is there treated as an ore of zinc. The residue has been subsequently smelted in a blast-furnace, and yielded characteristic spiegeleisen. Specimens of this were shown at the International Exhibition of 1862, and very good they appeared to be. The ore has been recommended as an antidote both to red-shortness and cold-shortness. It is stated that Pompton (New Jersey) pig-iron, which yields very red-short iron, will, in admixture with 15 % of franklinite, work up into horse-shoe iron; and that Scotch pig, which yields cold-short iron, produces iron of extraordinary toughness when puddled in admixture with 20 % of raw franklinite. It is suggested that the zinc and manganese, or the zinc alone, extract sulphur and phosphorus, and thus remove the chief causes of red-shortness and cold-shortness.[1] The merit of this alleged discovery is ascribed to Mr. Detmold.[2] Much was said about it at the Exhibition in 1851, when illustrative specimens were shown. Whether there may have been any confusion between the *post hoc* and the *propter hoc* with regard to the supposed influence of franklinite the future will decide.

Red hæmatite, red ore, anhydrous sesquioxide of iron.—When pure it contains 70 % of iron. It occurs crystallized, constituting specular iron ore, or micaceous iron ore, according to the dimensions and character of the crystals; and massive, or earthy, generally in reniform or botryoidal nodules, of a more or less fibrous and radiating structure. When in reniform lumps, the ore is sometimes termed "kidney ore." Some varieties are hard, compact, and rough to the touch; while others are soft, pulverulent in a greater or less degree, and greasy to the touch. The former frequently contains silica diffused in the state of quartz, sometimes in distinct crystals, at other times in minute crystals finely disseminated. When there is much silica diffused through the ore, unaccompanied with a sensible amount of alumina, lime, or magnesia, the pig-iron produced from it will be rich in silicon.

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[9] Handb. der Mineralchemie. 1860. p. 169.

[1] The Iron Manufacturer's Guide to the Furnaces, Forges, and Rolling Mills of the United States. By J. P. Lesley. New York. 1859. p. 423.

[2] Professor Wilson's Report on the New York Industrial Exhibition. 1854. p. 55.

This is a point of great practical consequence to the iron-master, as has been previously stated. In the Whitehaven district, two distinct varieties of red ore are recognized—the "hard" and the "soft." The former generally contain free silica in large excess, while the latter contain silica, which, although it may to a great extent be free, is yet associated with earthy bases diffused throughout in sufficient quantity to prevent the reduction of much silicon, and the consequent formation of very siliceous iron. Red hæmatite always produces a *characteristic red* streak when drawn across a piece of unglazed pottery. The magnificent specimens of specular iron ore from Elba are well known to every mineralogist. Beautiful micaceous ore is found at Hennock and Buckfastleigh, in Devonshire; and I have seen this purchased at certain smelting works for plumbago, to be used for purposes of lubrication. The massive and earthy varieties are extensively diffused; and in England they occur chiefly in Lancashire and Cumberland, in carboniferous limestone. In the carboniferous limestone at the Mumbles, near Swansea, is a vein of red ore which has been long worked. In the Devonian limestone of Berryhead, near Brixham, is also a vein of red ore, associated with sulphate of baryta. I have picked up beautiful cabinet specimens, mammillated or botryoidal, in this locality, which must not be confounded with that of brown hæmatite at Brixham. In the Belgian Department of the International Exhibition of 1862 were beautiful specimens of massive red ore, more or less pisolitic in structure, but of which the component rounded particles were flattened, and not spherical; they occur at the base of the carboniferous limestone cropping out along many miles of country, south of Liége and Huy.

Brown hæmatite, brown iron ore, limonite, hydrated sesquioxide of iron. $2Fe^2O^3, 3HO$.—When pure it contains 59·89 % of iron and 14·44 % of water. Under the generic term of brown hæmatite are included all the varieties of ore, in which the essential iron-yielding constituent is hydrated sesquioxide of iron. The finely fibrous, rich dark brown hæmatite of the mineralogist is a beautiful substance, and with the exception of the presence of from about 0·5 % to 5 % of silica, is not unfrequently met with in a state of purity; whereas by far the greater proportion of the ores in the present division are ochreous, yellow-brown, earthy, and outwardly most uninteresting objects. To these latter the term limonite appears specially applicable. Brown hæmatite always produces a decided *brownish yellow* streak when drawn across a piece of unglazed pottery, and by this character alone it may be immediately distinguished from red hæmatite. The most beautiful British specimens of brown hæmatite which I have seen have come from Restormel, in Cornwall. The chief locality, however, of this ore is the Forest of Dean, in Gloucestershire, where it has undoubtedly been worked from very ancient times. The remarks previously made concerning the presence of silica in red iron ore apply equally to brown iron ore. In specimens of a compact brown hæmatite which were sent to me some years ago from Bristol, and reported to have been procured in the vicinity, particles of colourless quartz and crystallized

reddish sulphate of baryta were diffused pretty uniformly through the mass. At Dowlais Iron-works, not very long since, a variety of hæmatite (whether red or brown I do not know) was smelted, which contained so much sulphate of baryta that a regulus rich in sulphide of barium flowed out of the furnace between the molten metal and the cinder. Earthy brown hæmatite occurs abundantly as a superficial deposit in the oölite of Northamptonshire, and recently one of a precisely similar appearance has been discovered in Lincolnshire.

The iron ores which are chiefly smelted in France and Belgium belong to the class of earthy-brown hæmatites. In the Belgian department of the International Exhibition of 1862 was an extensive series of these ores, with labels on each stating the per-centage of iron; and from these I inferred that their average yield does not much exceed 30 %. They closely resembled in external character the Northamptonshire ore.

Bog-iron ore and the so-called lake ores of Sweden and Finland are essentially brown hæmatites: they will be more particularly described hereafter. In Lower Canada bog-iron ore is smelted at the Radnor Forges, in the seignory of Cap de la Madelaine, on the Rivière au Lard, a tributary of the Champlain River. The pig-iron produced is chiefly applied to the manufacture of cast-iron railway wheels, of which specimens were exhibited in the International Exhibition of 1862, which have travelled 150,000 miles without showing signs of any very great wear.

Spathic carbonate, sparry iron ore, sphærosiderite, crystallized carbonate of protoxide of iron. FeO,CO^2.—It is anhydrous, and when pure contains 48·275 % of iron. I have not met with the record of any trustworthy analysis of the mineral in a state of purity. It generally contains a considerable proportion of carbonate of protoxide of manganese and carbonate of magnesia. Rammelsberg establishes the four following classes of spathic ores: 1. With from 0 % to 4 % of protoxide of manganese; 2. With from 6 % to 11 % of protoxide of manganese; 3. With a still larger proportion of manganese; 4. With a considerable proportion of magnesia. Illustrative examples from the series of analyses of spathic ore collected by Rammelsberg are now subjoined[3]:—

	I.		II.		III.		IV.	
	1.	2.	3.	4.	5.	6.	7.	8.
Carbonic acid	38·16	38·41	39·2	40·3	38·22	38·35	42·10	39·51
Protoxide of iron	60·00	53·06	53·5	45·6	43·59	36·81	44·56	51·15
Protoxide of manganese	...	4·20	6·5	11·7	17·87	25·31	...	1·62
Magnesia	...	2·26	0·7	2·4	0·24	...	11·65	7·72
Lime	1·84	1·12	...	...	0·08	...	...	...
	100·00	99·05	99·9	100·0	100·00	100·47	98·31	100·00

[3] Handb. der Mineralchemie. p. 222.

1. Compact sphærosiderite, from Burgbrohl, on the "Laacher See." By G. Bischof.—2. White, crystallized, from Bieber, near Hanau. By Glasson.—3. From Vic-Dessos, Pyrenees. By Berthier.—4. From Allevard, Isère, France. By Berthier.—5. Sphærosiderite in basalt, from Alte Birke, near Eisern, Siegen. By Schnabel.—6. Ehrenfriedersdorf, Saxony. By Magnus.—7. From Schaller Erbstolln, at Pöhl, in Saxon Voigtland. By Fritzsche.—8. From Mitterberg, Tyrol. By Khuen.

The most renowned and important locality of spathic ore in Europe is the Erzberg, near Eisenerz, in Styria, where it occurs in enormous quantity, and has been worked from ancient times. The ore is contaminated with a small quantity both of iron and copper-pyrites; and at the Stahlberg, near Müsen in Prussia, the latter is picked out by hand. In every case the ore is carefully calcined previously to smelting, whereby the sulphur is so effectually expelled that what remains has no injurious effect on the quality of the iron produced. Siegen, in Prussia, is also rich in fine spathic ore, of which a magnificent series were shown in the Zollverein Department of the International Exhibition of 1862. In England it is found in the Brendon Hills and Exmoor, Somersetshire. This ore has long enjoyed high repute as yielding manganesiferous pig-iron well adapted for the production of steel.

Argillaceous iron ores, clay or clay-band ironstones, impure earthy carbonates of protoxide of iron.—They owe their name to their clay-like appearance. They are compact, earthy in structure, varying in colour from light brown to black, and they are frequently seamed with cracks, filled with matter differing from the ore itself. When they are deep brown or black in colour, and contain a considerable proportion of coaly matter, say about 10 % or upwards, they are termed black-band ironstones. This kind of iron ore consists essentially of carbonate of protoxide of iron in intimate admixture with various matters, of which the most frequent are carbonate of protoxide of manganese, carbonate of lime, carbonate of magnesia, silicate of alumina in the state of clay, potash, phosphoric acid, sulphur in the state of bisulphide of iron, organic matter, and a little water of combination. They occur interstratified with the shales of the coal measures in nodules or in continuous beds. They are found to a workable extent in the coal fields of Yorkshire and Derbyshire, Warwickshire, North Staffordshire, South Staffordshire, and Worcestershire; the Clee Hills; South Wales; North Wales, and in Scotland. Argillaceous ores occur abundantly in the Lias of Yorkshire; they are also found in the Wealden, and were formerly raised and smelted in Sussex; beds of them may be seen in the cliffs near Hastings, and water-worn lumps picked up abundantly on the shore below; and they are not absent from the Tertiaries. The fishermen dredge up off the coast of the Isle of Wight rounded lumps of ore from the last named formations, and I have seen truckfuls of such lumps at the Ebbw Vale Iron-works, having been delivered at Cardiff, and there sold at 10s. per ton.

The shale in which many of the coal-measure ironstones are im-

bedded adheres to them with great tenacity; but by the action of the atmosphere it disintegrates and falls off. The time of exposure requisite thus to separate the shale varies considerably with the ores of different localities. Thus, in South Wales the adhesion of the shale is the cause of much complaint.

Those who are engaged in raising coal and the associated ironstones would do well never to throw anything away, of the nature of which they have not reason to be absolutely certain. During the last few years I have known several instances in which ironstones previously rejected as worthless have been found on examination to contain a large amount of iron, and, consequently, to possess considerable value. As a striking example of this may be adduced the ironstone occurring in association with coal in the district of Merthyr-Tydvil, and known as Duffryn Brass. It is only a few years ago that its nature was ascertained. It is heavy, stone-like, and brownish-grey in colour, and has sold as high as 14*s.* per ton. I am indebted to Mr. E. Riley for the following analysis of a specimen of it:—

Carbonate of protoxide of iron	58·48
Carbonate of protoxide of manganese	0·71
Carbonate of lime	10·68
Carbonate of magnesia	21·90
Phosphate of lime	0·09
Bisulphide of iron	0·09
Coal	8·95
	100·90

Another remarkable example is furnished by the black-band ironstone of Scotland, which has contributed enormously to the wealth of the Scotch iron-masters. Its nature and value were first discovered about the year 1800 by the late Mr. Mushet, to whom we are further indebted for much valuable information concerning the history of the development and progress of the smelting and manufacture of iron in Great Britain. Mr. Mushet, moreover, made numerous and important experimental investigations on the subject of the extraction and working of iron, which, considering the period when he lived and the incessant demands upon his time in the management of business connected with iron-works, were in a high degree creditable and praiseworthy.

In the International Exhibition of 1851 were specimens of Scotch black-band ironstone, which, according to my colleague, Mr. W. Smyth, attracted the attention of an observant Prussian mining official, who very shortly afterwards recognized the existence of similar ore in Westphalia, which previously had been regarded only as useless shale; and the further discovery has been made that some of the ore in this locality contains as much as 40 % of phosphate of lime.

The mineral species which I have observed in the argillaceous ores of the coal measures are as follow: iron pyrites, copper pyrites, zinc-blende, galena, millerite (capillary sulphide of nickel), and sulphate of iron. Zinc-blende may occasionally be observed lining or filling up in a greater or less degree cracks in the ore. I have remarked that in

some nodules of septarian structure, zinc-blende was present in very large quantity in the cracks towards the exterior, while none existed in those towards the centre. It has been clearly introduced from without by aqueous agency. Millerite has been found in cavities in ironstone at the Merthyr-Tydvil district, especially in the lowest of the three courses constituting the Spotted Vein Mine, at Ebbw Vale, Blaina, and Pontypool.

Tables of Analyses of British Iron Ores.

The first International Exhibition in 1851 contained a very extensive and highly interesting series of British ores, collected with great labour and expense by my friend, Mr. S. H. Blackwell, of Dudley, and afterwards presented by him to the Museum of Practical Geology. Mr. Blackwell offered to place at my disposal the sum of 500*l.* towards defraying the cost of analysing all the more important of these ores. The offer was accepted; and, with this view, I immediately engaged the services of two expert and trustworthy analysts, Mr. Allan B. Dick, of Edinburgh, and Mr. John Spiller, of London. The services of Mr. Edward Riley were also secured; but this gentleman shortly afterwards was appointed chemist to the Dowlais Iron-works, whither he proceeded. Messrs. Dick and Spiller were incessantly occupied with the work between two and three years, at salaries of 100*l.* per annum each. Additional analyses have been subsequently made in my laboratory by Mr. Charles Tookey, who has had very great experience as an analyst, and whose results may be thoroughly relied on. I need hardly observe that the sum of 500*l.* did not suffice for all the outlay connected with this laborious investigation. What was further required has been defrayed partly out of the sum of 50*l.* per annum allowed me by the Government for miscellaneous expenses connected with the laboratory, and partly, though to a less amount, out of my private funds. The selection and sampling of the specimens for analysis were undertaken by Mr. Kenyon Blackwell, at the request of his brother, the donor of the collection. When the ore occurred in contiguous beds, which were gotten and raised together, the sample analysed was prepared from an equal weight of each. Some of the analyses, I should also add, have been executed in my laboratory by Mr. Tookey, at the request and cost of private individuals. A series of analyses of the Dowlais iron ores, by Mr. Riley, have been communicated by the Dowlais Iron Company, and a few also by the late Mr. E. Rogers, of Abercarn, near Newport, Monmouthshire. Other analyses have been extracted from published works, especially the valuable Blue Book on Cast-iron Experiments, presented to the House of Commons, July 30, 1858: these were made in the Chemical Laboratory of the Arsenal at Woolwich, under the direction of Mr. Abel, chiefly, I believe, by Mr. John Spiller. In every case the authority and reference will be found stated. The initials over the columns are those of the names of the analysts: A. D., Allan Dick; J. S., John Spiller; E. R., Edward Riley; C. T., Charles Tookey. All the

analyses to which these initials are attached have been made in the metallurgical laboratory of the Royal School of Mines, in Jermyn-street. Where no initials are given, the names of the analysts will be found under the respective descriptive notices. A large proportion of these analyses have been published, at the expense of Government, in the work entitled "The Iron Ores of Great Britain," of which four parts have already appeared.

In all Mr. Dick's analyses the ore was weighed after drying at 100° C., so that in the columns headed with A. D. the combined water alone is given. In nearly all Mr. Spiller's analyses the ore was weighed without previous drying, so that in the columns headed with J. S. both hygroscopic and combined water will be found. When the number in the line for water faces a bracket including hygroscopic and combined water, it indicates that the ore was analysed without previous drying, but that the water in the two states was not separately determined. In some analyses the combined water appears very small compared with the amount of clay existing in the ore: *e.g.*, see Nos. 62 and 63 in the table of Argillaceous Ores from the Coal Measures.

In Mr. Dick's analyses the alkali was not separately determined in that part of the ore which dissolved in hydrochloric acid; and, consequently, when alkali appears in his analyses, it will be found under the ignited insoluble residue.

The amount soluble is not to be regarded as strictly determinate; for it may vary according to the strength of the acid, time of digestion, etc. However, I considered it desirable in many cases to state the composition of the soluble and insoluble portions separately, as iron ores are now frequently assayed by *wet* methods, and it becomes important to know how much may remain undissolved. It is also desirable to ascertain whether soluble silica is present. Besides, the facts elicited from this mode of presenting the analytical results may be interesting in a purely scientific point of view. Thus, in the ignited insoluble residue of the argillaceous ores, alkali is always to be found, and generally in larger proportion than in the soluble part. I directed special attention to this point, which has been carefully and repeatedly established. The residue in this class of ores for the most part has the composition of fire-clay.

It is not to be inferred that a blank space in the columns necessarily indicates the absence of the substance. Thus, it was ascertained that frequently a trace of sesquioxide of iron existed in argillaceous ores; but I did not consider it necessary to determine the amount, except when it was present in sensible proportion.

When analyses of the soluble and insoluble portions are given separately, the silica in the upper part of the table indicates soluble silica, and that in the lower part insoluble silica.

TABLE I.—MAGNETIC OXIDE.

	E. R.
Sesquioxide of iron	62·20
Protoxide of iron	16·20
Protoxide of manganese	0·14
Alumina	2·28
Lime	2·34
Magnesia	0·37
Silica	0·24
Phosphoric acid	0·10
Bisulphide of iron	0·07
Water { hygroscopic	0·28
Water { combined	0·34
Ignited insoluble residue	16·26
	100·82
Ignited insoluble residue.	
Silica	9·42
Alumina	1·53
Protoxide of iron	1·12
Lime	3·18
Magnesia	1·45
Potash } Soda }	0·10
	16·80
Iron, total amount	57·01

TABLE II.—RED HÆMATITES.

	A. D. 1.	A. D. 2.	2a.	A. D. 3.	J. S. 4.	4a.	4a.	5.
Sesquioxide of iron	95·16	90·36	98·71	86·50	94·23	90·94	91·40	66·55
Protoxide of iron	-	-	-	-	-	-		1·13
Protoxide of manganese	0·24	0·10	trace	0·21	0·23	0·25[2]		1·13
Alumina	-	0·37	-	-	0·51	trace		1·75
Lime	0·07	0·71	trace	2·77	0·05	0·99	0·95	8·55
Magnesia	-	0·06	-	1·46	trace	trace		1·12
Potash	-	-	-	-	-	-		0·19
Soda	-	-	-	-	-	-		0·07
Silica	-	-	-	-	-	-		0·31
Carbonic acid	-	-	-	2·96	-	0·78[3]		5·73
Phosphoric acid	trace	trace	trace	trace	minute trace	trace		1·02
Sulphuric acid	Do.	do.	-	0·11	0·09	0·24		1·31
Bisulphide of iron	Do.	0·06	-	-	0·03	-		
Water { hygroscopic	-	-	-	-	0·39	-		2·12
Water { combined	-	-	-	-	0·17	-		
Organic matter	-	-	-	-	-	-		0·38
Ignited insoluble residue	5·68	8·54	1·00	6·55	5·18	6·68	6·62	10·36
	101·15	100·20	99·71	100·56	100·88	99·88		101·72
Ignited insoluble residue.								
Silica	5·66	7·05	The insoluble residue was silica in the state of quartz.	6·18	4·90	The insoluble residue consisted of silica with a very small quantity of alumina.		8·59
Alumina	0·06[1]	1·06		0·30[1]	0·12			1·04[1]
Sesquioxide of iron	-	0·19		-	traces			-
Lime	-	trace		-	traces			0·85
Magnesia	-	-		-	-			0·27
Potash	-	-		-	-			0·23
Soda	-	-		-	-			0·08
	5·72	8·30		6·48	5·02			11·06
Iron, total amount	66·60	63·25	69·10	60·55	65·98	63·66		47·47

[1] With trace of iron. [2] Estimated as MnO^2. [3] By calculation.

TABLE III.—BROWN HÆMATITES.

	A. D. 1.	A. D. 2.	A. D. 3.	A. D. 4.	A. D. 5.	E. R. (D.) 6.	E. R. (D.) 7.	A. D. 8.	C. T. 9 a.	9 b.
Sesquioxide of iron	52·83	90·05	32·76	89 76	48·98	59·05	51·87	89·34	35·91	27·93
Protoxide of iron	-	-	-	-	0·24	-	-	-	6·57	5·08
Protoxide of manganese	0·81	0·08	traces	0·04	0·16	0·09[2]	0·43[2]	0·33	0·05	traces
Alumina	-	trace	0·05	0·63	0·12	trace	4·01	0·33	27·95	34·57
Lime	14·61	0 06	0·25	0·49	14·07	0·25	0·52	0·33	0·60	0·91
Magnesia	5 70	0·20	0·25	0·40	10·21	0·28	0·17	0·20	0·20	0·62
Potash	-	-	-	-	-	-	-	-	0 49	-
Silica	trace	-	0·07	-	-	34·40	36·03	-	9·75	9·87
Carbonic acid	18·14	-	-	-	20·75	-	-	-	-	-
Phosphoric acid	0·32	0·09	0·09	0·13	0·06	0·14	0·49	0·13	none	traces
Sulphuric acid	0·28 }	trace }	traces }	traces	traces	-	-	trace	-	-
Bisulphide of iron	- }	}	}	-	-	0·09	0·03[3]	trace	-	-
Water { hygroscopic	-	-	-	-	-	0·24	0·80 }	- }	18·60	19·36
Water { combined	4·75	9·22	3·55	7·05	5·18	6·14	5·80 }	8·83 }		
Organic matter	1·30	-	-	-	-	-	-	-	-	-
Ignited insoluble residue	0·04	1·07	63·38	2·57	0·86	-	0·05[4]	1·70	-	-
Titanic acid	-	-	-	-	-	-	-	-	-	3·51
	98·78	100·77	100·40	101·07	100·63	100·68	100·20	101·19	100·12	101·85
Ignited insoluble residue.									Insoluble residue not analysed separately, as the ore was fused with alkaline carbonates.	
Silica		0·92	63·45	2·14	0·79			1·42		
Alumina		0·14[1] }	traces	0·35	0·05			0·19		
Sesquioxide of iron ...		- }		0·04	0·01			0·05		
Lime		-	-	0·02	-			-		
		1·06	63·45	2·55	0·85			1·66		
Iron, total amount ...	36·98	63·04	22·93	62·86	34·46	41·34	36·31	62·60	30·25	23·50

[1] With trace of iron. [2] Estimated as MnO^2. [3] Sulphur. [4] Copper.

TABLE IV.—BROWN HÆMATITES, CHIEFLY FROM THE OOLITE.

	J. S. 1. a.	J. S. 1. b.	E. R. 2.	E. R. 3. a.	E. R. 3. b.	A. D. 4.	5.
Sesquioxide of iron	52·20	51·93	34·41	50·31	50·48	74·12	76·00
Protoxide of iron	trace		trace	trace		-	trace
Protoxide of manganese	0·51		0·27	0·51	0·45	0·57	0·40
Alumina	7·13		6·19	7·25		1·55	2·30
Lime	7·13	7·39	25·68	11·76	11·87	0·76	0·41 } [2]
Magnesia	0·57	0·54	0·85	0·62	0·60	0·18	0·11 }
Potash	-	-	-	-	-	-	-
Silica	1·60	1·77	0·89	0·22	0·35	0·43	-
Carbonic acid	4·92		18·45	7·98	7·80	0·57	-
Phosphoric acid	1·26		1·47	1·28		3·17	1·03
Sulphuric acid	-		0·07	-		trace	-
Bisulphide of iron	0·03		0·30	0·17		0·06	-
Water { hygroscopic	-		-	-		-	1·80
Water { combined	11·37	11·28	6·97	11·00	11·07	11·89	12·40
Organic matter	-		-	-	-	trace	-
Ignited insoluble residue	13·55	13·59	5·82	9·33	9·34	7·15	5·33
	100·27		101·37	100·43		100·45	99·78
Ignited insoluble residue.							
Silica	11·56		5·80	8·58	8·54	5·60	Insoluble residue consisted almost wholly of silica with a trace of mica.
Alumina	0·26 }		0·21	0·27	0·35	1·36	
Sesquioxide of iron	0·66 }			0·22	0·26	0·20	
Lime	0·33		0·04	0·16	0·11	-	
Magnesia	0·11		0·02	trace		trace	
Potash	-		-	0·11[1]		undetermined	
	12 92		6·07	9·34		7·16	
Iron, total amount	37·00		24·09	35·37		52·05	53·20

[1] With trace of soda.

[2] Estimated as carbonates.

TABLE IV.—BROWN HÆMATITES, CHIEFLY FROM THE OOLITE—*continued.*

	6.	A. D. 7.	A. D. 8.	A. D. 9.	C. T. 10.	C. T. 11.	C. T. 12.	E. R. (D.)[1] 13.
Sesquioxide of iron	56·20	-	38·04	3·19	44·67	58·10	55·21	53·43
Protoxide of iron	trace	33·29	10·54	12·34	0·86	-	-	-
Protoxide of manganese	0·20	1·11	0·69	trace	0·44	0·88[5]	0·95[5]	1·60[5]
Alumina	2·43	4·62	12·35	3·36	7·85	3·00	2·75	4·19
Lime	0·49 }[2]	0·50	trace	34·82	9·29	4·15	0·45	0·84
Magnesia	0·17 }[2]	7·96	4·13	1·67	0·66	0·96	1·15	0·72
Potash	-	-	-	0·18	-	-	-	-
Silica	-	1·99	1·96	2·13	0·48	-	-	24·81
Carbonic acid	-	24·79	0·16	31·92	6·11	1·08	-	trace
Phosphoric acid	0 84	0·22	0·26	0·26	0·55	1·40	0·42	0·87
Sulphuric acid	-	trace	trace	0·10	-	-	0·16	-
Bisulphide of iron	-	0·13	0·13	0·06	trace[3]	-	-	trace[3]
Water { hygroscopic	1·16	-	-	- }	16·31	16·46	13·11	13·61
Water { combined	9·74	0·54	6·92	1·76 }				
Organic matter	-	0·08	0·19	trace	-	-	-	-
Ignited insoluble residue	29·07	24·09	24·61	7·36	13·10	13·75	25·15	-
	100·30	99·32	99·98	99·15	100·32	99·78	99·35	100·07
Ignited insoluble residue.								
Silica	The insoluble residue consisted of silica with a little mica.	17·50	21·28	6·18	11·86	11·70	19·65	1·42
Alumina		3·27	2·67	0·61	1·25[4]	1·95[6]	4·95[4]	0·19
Sesquioxide of iron		3·31	-	0·18	-	Of the 11·70 of silica 7·45 was in combination, and 4·25 existed as sand.	-	0·05
Lime		trace	trace	0·05	trace		0·25	-
Magnesia		0·81	0·22	0·04	-		trace	-
Potash		0·20	0·38	-	-		-	-
		25·09	24·55	7·06	13·11	13·65	24·85	1·66
Iron, total amount	39·34	28·28	34·83	11·98	31·94	40·67	38·65	37·44

[1] E. R. (D.) indicates that the analysis was made by Mr. Riley at Dowlais. [2] Estimated as carbonates. [3] Sulphur. [4] With trace of iron. [5] Estimated as MnO^2. [6] With traces of iron and lime.

TABLE V.—SPATHIC CARBONATES.

	J. S. 1. a.	J. S. 1. b.	A. D. 2.	C. T. 3.	C. T. 4.	J. S. 5.	J. S. 6.
Protoxide of iron	10·77		49·47	49·77	-	43·84	17·91
Sesquioxide of iron	49·50		-	0·81	71·11	0·81	-
Protoxide of manganese	3·06	2·90	2·42	1·93	6·60[2]	12·64	7·64
Alumina	0·43		trace	-	0·40	-	-
Lime	5·68	5·66	3·47	3·96	0·56	0·28	24·80
Magnesia	1·20	1·42	3·15	2·83	1·90	3·63	6·17
Potash	-		-	-	-	-	-
Silica	0·29		1·20	-	-	-	-
Carbonic acid	14·49	14·70	37·71	37·20	0·13	38·86	41·75
Phosphoric acid	0·01		trace.	trace.	0·22	-	trace.
Sulphuric acid	trace.		trace.	-	-	-	-
Bisulphide of iron	0·03		0·08	0·04[1]	-	-	0·11
Water { hygroscopic	1·81 }	8·40	-	0·30	12·40	0·18	0·38
Water { combined	6·63 }						
Organic matter	trace.		trace.	-	-	-	-
Ignited insoluble residue	6·90		3·77	3·12	6·32	0·08	0·47
	100·80		101·27	99·96	99·64	100·32	99·23
Ignited insoluble residue.							
Silica	6·35		3·73	Insoluble residue not analysed. It consisted almost wholly of quartz with a small quantity of fluoride of calcium.	4·09	0·0695	0·40
Alumina	0·41		0·06		-	0·0097	-
Sesquioxide of iron	0·07		-		1·97	0·0020	0·07[3]
Lime	0·01		-		-	0·0004	trace.
Magnesia	0·01		-		-	trace.	-
Potash	0·05		-		-	-	-
	6·90		3·79		6·06	0·0816	0·47
Iron, total amount	43·02		38·56	38·95	49·78	34·67	13·98

[1] Sulphur. [2] Estimated as MnO^2. [3] Estimated as FeO.

TABLE VI.—ARGILLACEOUS IRON ORES FROM THE COAL MEASURES.

	Yorkshire.						Derbyshire.			
	J. S. 1.	J. S. 2.	2a.	J. S. 3.	J. S. 4.	J. S. 5.	J. S. 6.	J. S. 7.	J. S. 8.	J. S. 9.
Protoxide of iron	35·38	36·14	47·13	41·77	39·38	39·87	33·72	37·99	35·74	33·56
Sesquioxide of iron	1·20	0·61	-	1·96	1·24	0·53	-	1·04	1·26	1·66
Protoxide of manganese	0·94	1·38	2·20	1·13	0·95	1·38	1·01	1·51	1·23	0·96
Alumina	0·80	0·52	-	0·58	0·82	0·74	0·67	0·41	0·47	0·73
Lime	2·78	2·70	2·58	2·55	2·26	2·12	3·99	4·53	2·94	3·02
Magnesia	2·22	2·05	1·12	3·71	3·72	2·64	5·43	3·30	2·70	2·81
Carbonic acid	25·41	26·57	32·55	31·39	29·38	28·47	28·64	29·92	26·74	25·63
Phosphoric acid	0·48	0·34	0·96	0·75	0·47	0·69	0·41	0·80	0·66	0·79
Sulphuric acid	trace	trace	-	trace	-	trace	trace	trace	trace	trace
Bisulphide of iron	0·18	0·10	trace	Do.	trace	0·05	0·13	0·06	0·05	0·26
Water { hygroscopic	0·74	0·61	0·25	0·55	0·68	0·59	0·57	0·74	0·68	0·74
Water { combined	1·11	1·16	1·75	1·15	1·41	1·21	0·87	1·47	1·49	1·51
Organic matter	0·23	2·40	0·30	0·86	0·54	0·83	0·36	1·42	0·76	1·57
Ignited insoluble residue	28·00	25·27	11·30	14·16	19·35	20·30	23·55	16·35	24·83	26·46
	99 47	99·85	100·14	100·56	100·20	99·42	99·35	99·54	99·55	99·70
Ignited insoluble residue.										
Silica	19·13	17·37		8·93	12·16	13·50	16·02	10·04	16·07	17·13
Alumina	6·83	6·22		4·21	5·60	5 39	5·74	5·16	6·62	7·76
Sesquioxide of iron	0·57	0·84		0·43	0·45	0·77	0·79	0·45	0·92	0·50
Lime	0·11	trace		trace	trace	trace	trace	0·06	0·07	0·15
Magnesia	0·07	0·12		0·14	0·17	0·13	0·06	0·07	0·26	0·25
Potash	0·78	0·65		0·43	0·37	0·18	0·47	0·55	0·66	0·74
	27·49	25·20		14·14	18·75	19·97	23·08	16·33	24·60	26·53
Iron, total amount	28·76	29·12	36·70	34·16	31·82	31·92	26·79	30·60	29·32	27·61

TABLE VI.—ARGILLACEOUS IRON ORES FROM THE COAL MEASURES—*continued.*

	Derbyshire—*continued.*					South Staffordshire.				
	J. S. 10.	J. S. 11.	J. S. 12.	J. S. 13.	J. S. 14.	J. S. 15.	A. D. 16.	A. D. 17.	A. D. 18.	18 a.
Protoxide of iron	38·97	28·27	40·01	33·31	39·55	43·81	45·35	37·69	54·12	50·40
Sesquioxide of iron	0·88	1·01	1·60	1·47	2·71	-	-	-	-	-
Protoxide of manganese	1·09	1·02	1·26	2·18	1·50	0·98	0·56	0·61	2·05	0·75
Alumina	0·38	0·33	0·58	0·95	1·14	1·05	0·61	8·24	0·78	-
Lime	1·58	13·94	2·78	2·32	3·32	1·52	2·60	2·72	2·21	1·70
Magnesia	4·62	9·18	2·88	2·44	2·85	1·15	1·22	2·60	0·62	1·19
Potash	-	-	-	-	-	-	-	0·43	trace	-
Silica	-	-	-	-	-	0·46	0·67	18·11	2·11	-
Carbonic acid	30·14	37·61	29·72	24·83	28·63	28·22	30·21	25·92	35·25	33·70
Phosphoric acid	0·48	0·74	0·34	0·62	1·12	0·83	0·46	0·66	0·69	0·45
Sulphuric acid	trace	trace	trace	-	trace	trace	trace	trace	trace	-
Bisulphide of iron	0·05	0·04	0·09	0·13	0·05	0·30	0·20	0·22	0·40	trace
Water {hygroscopic	0·64	0·18	0·45	0·70	0·51	0·54	1·64	1·29	1·07	0·30
Water {combined	1·02	0·73	1·12	1·87	1·24	1·32				1·41
Organic matter	0·30	0·92	1·38	1·85	1·14	0·88	1·59	1·56	1·36	0·50
Ignited insoluble residue	19·10	6·39	17·84	27·42	15·80	18·80	15·87	-	-	9·70
	99·25	100·36	100·05	100·09	99·56	99·86	100·98	100·05	100·66	100·10
Ignited insoluble residue.										
Silica	11·90	3·55	11·19	17·24	10·22	12·40	9·96	Not analysed separately.	Not analysed separately.	
Alumina	5·55	1·98	5·33	7·90	4·51	5·11	5·09			
Sesquioxide of iron	0·59	0·41	0·70	1·22	0·78	0·39	0·54			
Lime	0·04	trace	trace	-	0·06	0·15	trace			
Magnesia	0·20	0·09	0·17	0·27	0·03	trace	0·04			
Potash	0·67	0·16	0·34	0·49	0·48	0·42	0·36			
	18·95	6·19	17·73	27·12	16·08	18·47	15·99	25·51	3·43	
Iron, total amount	31·34	22·98	32·73	27·79	33·20	34·35	35·74	29·42	42·26	39·45

Table VI.—Argillaceous Iron Ores from the Coal Measures—*continued.*

South Staffordshire—*continued.*

	18 b.	18 c.	A. D. 19.	19 a.*	19 b.	A. D. 20.	A. D. 21.	J. S. 22. a.	J. S. 22. b.	23 a.
Protoxide of iron	48·43	48·96	46·30	49·28	52·50	45·86	40·28	30·96		44·74
Sesquioxide of iron	-	-	-	-	-	-	-	-		-
Protoxide of manganese	0·84	1·06	1·44	1·24	1·00	0·96	0·54	0·78		0·50
Alumina	-	-	0·44	-	-	0·42	0·52	0·13		-
Lime	1·00	3·73	0·76	1·29	1·06	1·17	0·84	1·84	1·76	1·70
Magnesia	1·32	0·84	0·94	0·92	0·58	1·65	1·33	2·90	3·03	2·05
Potash	-	-	-	-	-	-	-	-		-
Silica	-	-	0·12	-	-	0·42	0·87	0·15		-
Carbonic acid	32·53	33·60	30·44	32·83	33·47	31·02	26·53	22·13	21·94	30·63
Phosphoric acid	0·59	0·72	0·74	0·66	0·75	0·21	0·30	0·26		0·72
Sulphuric acid	-	-	trace	-	-	trace	trace	trace		-
Bisulphide of iron	trace	trace	0·07	trace	trace	0·10	0·09	0·12		-
Water, hygroscopic	0·34	0·30	1·38	0·26	0·26	1·08	1·69	0·56	0·60	0·34
Water, combined	1·61	1·28		1·59	1·34			1·83	1·65	1·51
Organic matter	0·52	0·35	1 14	0·68	0·25	0·90	1·99	0·10		trace
Ignited insoluble residue	12·41	9·40	15·26	11·09	8·70	15·90	24·06	37·90	37·76	18·17
	99·59	100·24	99·03	99·84	99·91	99·69	99·04	99·61		100·36
Ignited insoluble residue.										
Silica			10·17			10·26	18·20	26·35		
Alumina			4·36			5·44	4·46	9·45		
Sesquioxide of iron			0·13			0·40	0·52	1·15		
Lime			trace			0·20	0·68	traces		
Magnesia			-			0·20	0·14	0·21		
Potash			undetermined			undetermined	undetermined	0·74		
			14·66			16 50	24·00	37·90		
Iron, total amount	37·97	38·32	36·14	38·60	41·02	35·99	31·70	24·88		35·25

TABLE VI.—ARGILLACEOUS IRON ORES FROM THE COAL MEASURES—*continued.*

	South Staffordshire—*continued.*									
	J. S. 23.	23 a.	23 b.	23 c.	A. D. 24.	A. D. 25.	A. D. 26.	A. D. 27.	A. D. 28.	A. D. 29.
Protoxide of iron	48·63	51·52	47·70	43·33	50·60	43·55	46·39	47·87	49·61	44·20
Sesquioxide of iron	-	-	-	-	-	-	-	-	-	-
Protoxide of manganese	1·29	0·56	0·84	0·60	3·30	1·65	1·01	1·12	0·98	2·43
Alumina	0·57	-	-	-	0·24	0·23	0·54	0·43	0·50	0·37
Lime	4·45	1·28	2·85	4·53	1·19	1·53	1·03	1·00	1·86	0·96
Magnesia	0·80	1·66	2·45	2·66	1·98	4·65	1·33	1·27	1·86	1·04
Potash	-	-	-	-	-	-	-	-	-	-
Silica	0·33	-	-	-	0·27	0·34	-	-	-	0·98
Carbonic acid	32·16	33·17	34·36	32·64	35·47	34·00	30·00	30·96	33·05	29·03
Phosphoric acid	0·31	0·60	0·56	0·78	0·23	0·15	0·11	0·07	0·34	0·66
Sulphuric acid	0·06	-	-	-	trace	0·06	0·10	0·08	0·10	0·05
Bisulphide of iron	0·16	-	-	0·16	0·13	0·47	0·17	0·17	0·17	0·26
Water { hygroscopic	0·32	0·25	0·32	0·28	0·47	0·64	1·50	1·18	1·30	undetermined
Water { combined	1·23	1·20	1·23	1·36						
Organic matter	0·28	trace	0·25	0·30	undetermined	undetermined	0·21	0·41	1·24	2·68
Ignited insoluble residue	9·40	10·07	9·87	13·21	5·52	11·95	18·39	15·95	10·02	17·04
	99·99	100·31	100·43	99·85	99·40	99·22	100·78	100·51	101·03	99·70
Ignited insoluble residue.										
Silica	5·88				3·31	7·47	11·71	10·52	6·26	No analysis of insoluble matter.
Alumina	3·07				1·63	3·47	6·04	5·02	2·35	
Sesquioxide of iron	0·04				0·38	0·84	0·57	0·33	0·53	
Lime	traces				0·08	0·19	0·09	0·13	0·03	
Magnesia	-				0·06	0·09	-	-	-	
Potash	0·11				undetermined	undetermined	0·28	0·38	0·39	
	9·10				5·46	12·06	18·69	16·38	9·56	
Iron, total amount	37·45	40·32	37·35	34·00	39·71	34·88	36·56	37·47	39·02	34·53

TABLE VI.—ARGILLACEOUS IRON ORES FROM THE COAL MEASURES—*continued.*

	SOUTH STAFFORDSHIRE—*continued.*									
	A. D. 30.	C. T. 31.	C. T. 32.	A. D. 33.	A. D. 34.	34 a.	C. T. 35.[2]	C. T. 36.	C. T. 37.	C. T. 38.
Protoxide of iron	33·19	46·56	33·92	39·51	52 04	48·00	49·04	49·30	42·34	40·39
Sesquioxide of iron	-	2·80	2·77	-	-	-	3·39	3·61	1·47	2·38
Protoxide of manganese	2·02	0·65	0·77	0·94	0·92	0·57	0·79	0·86	1·12	0·75
Alumina	7·71	0·70	0·67	1·12	1·30	-	0·21	0·34	0·59	0·19
Lime	1·24	1·13	2·45	2·11	0·53	1·10	0·70	0·69	3·89	7·30
Magnesia	1·04	1·18	4·11	2·76	0·85	1·21	0·57	0·45	1·48	2·16
Potash	0·90	0·23	0·14	-	-	-	0·10	0·09	-	0·07
Silica	22·48	0·54	0·09	-	-	-	0·27	0·23	0·35	0·18
Carbonic acid	20·94	30·08	26·89	28·08	32·31	30·70	30·80	32·05	30·91	33·35
Phosphoric acid	0·50	0·38	0·35	0·31	0·21	1·07	0·18	0·23	0·25	0·22
Sulphuric acid	0·04	-	-	trace	trace	-	-	1·27[1]	trace	-
Bisulphide of iron	0·41	0·13	0·15	0·05	0·13	0·18	0·11	0·13	0·06	0·11
Water, hygroscopic	undetermined	1·07	0·42	0·98	0·46	0·37	0·26	0·37	0·28	0·33
Water, combined			0·98			1·15	0·77	0·29	0 73	0·60
Organic matter	9·87	0·50	0·47	0·52	0·51	0·30	0·60	0·54	0·56	0·80
Ignited insoluble residue	-	13·77	25·55	22·96	11·14	15·70	12·15	9·42	15·50	10·52
	100·34	99·72	99·73	99·34	100·40	100·35	99·94	99·87	99·53	99·35
Ignited insoluble residue.										
Silica	Insoluble matter not analyzed separately.	7·72	18·14	16·31	6·63		7·67	5·99	10·82	6·56
Alumina		4·70	5·77	5·13	3·68		3·55	2·71	3·65	3·08
Sesquioxide of iron		0·39	0·40	0·85	0·43		0·36	0·21	0·11	0·37
Lime		0·11	0·20	trace	trace		0·09	0·17	traces	0·04
Magnesia		0·15	0·32	0·30	0·33		0·09	0·07		0·06
Potash		0·82	0·60	0·65	0·32		0·32	0·21	0·84	0·26
		13·89	25·43	23·24	11·39		12·08	9·36	15·42	10·37
Iron, total amount	26·01	38·56	28·87	31·34	40·84	37·70	40·81	41·06	34·41	33·44

[1] Sulphide of zinc.

[2] Traces of manganese were found in the insoluble residue of Nos. 35, 37, 38, 39.

TABLE VI.—ARGILLACEOUS IRON ORES FROM THE COAL MEASURES—*continued.*

	South Staffordshire—*continued.*			North Staffordshire.						
	C. T. 39.	A. D. 40.	A. D. 40 a.	A. D. 41.	A. D. 42.	J. S. 43.	A. D. 44.	A. D. 45.	J. S. 46.	A. D. 47.
Protoxide of iron	40·01	41·90	-	46·14	46·53	34·22	50·73	45·53	41·80	46·35
Sesquioxide of iron	2·46	-	4·51	-	-	0·68	0·45	5·00	-	3·00
Protoxide of manganese	0·75	0·72	-	1·40	2·54	2·87	1·86	1·74	2·16	1·61
Alumina	0·46	5·26	29·54	3·53	0·97	0·23	0·26	0·32	0·53	0·30
Lime	2·58	3·47	0·30	3·43	2·41	11·91	2·52	2·91	5·07	1·93
Magnesia	2·70	4·89	-	2·13	1·39	1·44	1·26	2·13	3·03	2·24
Potash	0·19	0·87	-	0·41	-	-	-	-	-	-
Silica	0·27	9·95	0·29	8·63	-	-	-	-	-	-
Carbonic acid	29·13	31·94	-	32·04	30·77	32·52	33·89	32·12	32·40	32·46
Phosphoric acid	0·21	0·22	-	0·61	0·69	0·87	0·73	0·86	1·40	0·67
Sulphuric acid	-	0·06	-	trace	0·04	0·12	0·08	0·08	trace	trace
Bisulphide of iron	0·06	0·56	-	0·10	0·34	0·35	0·30	0·37	0·04	0·15
Water: hygroscopic	0·39	-	-	-	-	0·23	Undetermined.	-	0·36	-
Water: combined	0·72	0·82	14·26	0·94	1·47	0·75		2·29	0·71	1·43
Organic matter	1·06	0·42	-	0·98	10·46	8·93	6·41	5·20	0·79	2·95
Ignited insoluble residue	18·77	-	50·51	-	2·27	4·57	0·72	1·95	10·81	7·29
	99·76	101·08	99·41	100·34	99·88	99·69	99·21	100·50	99 10	100·38
Ignited insoluble residue.										
Silica	13·45	Not analyzed separately.	41·49	Not analyzed separately.	1·93	8·13	0·38	1·36	7·32	5·78
Alumina	4·22		7·45		0·25	1·12	0·32	0·42	3·28	1·22
Sesquioxide of iron	0·59		-		0·05	0·33	-	0·06	0·20	0·11
Lime	0·08		0·18		0·03	traces	0·03	-	0·04	-
Magnesia	0·14		0·16		-		-	-	trace	-
Potash	0·18		Not sought for		0·20		0·14	0·05	0·09	0·18
	18·66	14·67	49·28	13·38	2·46	4·58	0·87	1·89	10·93	7·29
Iron, total amount	33·28	32·87		35·95	36·39	27·33	39·84	39·13	32·64	38·29

TABLE VI.—ARGILLACEOUS IRON ORES FROM THE COAL MEASURES—*continued.*

	North Staffordshire—*continued.*			Warwickshire.	Shropshire.				
								J. S. 53.	
	A. D. 48.	A. D. 49.	49 a.	49 b.	J. S. 50.	J. S. 51.	J. S. 52.	a.	b.
Protoxide of iron	48·33	51·07	45·71	48·70	48·28	46·30	44·33	45·08	45·12
Sesquioxide of iron	-	-	-	-	-	-	1·06	0·55	
Protoxide of manganese	2·99	2·36	1·20	0·90	0·82	0·82	1·00	1·69	1·78
Alumina	0·41	0·54		0·50	0·67	0·48	0·92	0·43	0·35
Lime	1·52	1·74	3·37	3·25	2·26	2·30	2·86	2·95	2·80
Magnesia	1·19	1·10	1·93	3·05	1·83	2·01	1·97	4·11	4·08
Potash	-	-		-	-	-	-	-	
Silica	-	-		4·85	-	-	-	0·57	0·52
Carbonic acid	32·76	33·63	33·50	36·89	32·98	31·68	30·92	34·04	34·00
Phosphoric acid	0·87	1·12	1·42	0·71	0·26	0·50	0·70	0·46	
Sulphuric acid	trace	trace	-	-	0·10	0·11	0·06	trace	
Bisulphide of iron	0·19	0·17	0·13	-	0·19	0·08	0·01	0·48	0·49
Water hygroscopic			2·64		0·24	0·28	0·35	0·30	
Water combined	0·85	0·99		1·15	0·62	0·81	0·95	0·72	
Organic matter	1·17	1·24	trace		0·62	0·62	0·38	0·23	
Ignited insoluble residue	9·28	5·18	9·66		11·19	13·24	14·35	8·32	8·38
	99·56	99·14	99·56	100·00	100·06	99·23	99·86	99·93	
Ignited insoluble residue.									
Silica	6·25	3·02			7·36	8·23	9·90	5·66	
Alumina	2·41	1·93			3·50	3·78	3·60	1·96	
Sesquioxide of iron	0·21	0·12			0·53	0·69	0·56	0·26	
Lime	-	-			0·08	trace	0·12	0·16	
Magnesia	-	-			trace	0·07	trace	0·09	
Potash	0·22	0·28			0·10	0·33	0·24	trace	
	9·09	5·35			11·57	13·10	14·42	8·13	
Iron, total amount	37·83	39·88	35·55	37·88	37·92	36·49	35·61	35·63	

TABLE VI.—ARGILLACEOUS IRON ORES FROM THE COAL MEASURES—*continued.*

	Shropshire—*continued.*				South Wales.					
	J. S. 54. a.	J. S. 54. b.	J. S. 55.	J. S. 56.	A. D. 57.	A. D. 58.	58 a.	A. D. 59.	59 a.	59 b.
Protoxide of iron	38·55	38·49	44·19	51·45	45·22	36·10	51·28	41·22	47·02	47·60
Sesquioxide of iron	-	-	-	-	-	-	-	-	-	-
Protoxide of manganese	1·31	1·15	0·99	0·54	1·05	0·76	1·11	1·07	1·00	0·46
Alumina	trace		0·41	0·43	0·58	0·48	-	0·59	-	-
Lime	2·54	2·63	1·63	2·13	1·63	1·07	0·78	2·89	2·57	0·77
Magnesia	4·65	4·82	3·40	0·42	3·04	4·52	0·53	3·38	3·23	2·30
Potash	-		-	-	-	-	-	-	-	-
Silica	0·12	0·22	0·37	-	-	-	-	-	-	-
Carbonic acid	29·80	29·81	32·02	33·31	31·58	27·33	33·32	30·07	34·30	32·90
Phosphoric acid	0·25	0·22	0·29	0·23	0·38	0·18	0·74	0·76	0·92	0·71
Sulphuric acid	0·06		0·06	-	trace	trace	-	trace	-	-
Bisulphide of iron	0·37		0·43	0·02	0·71	0·11	0·06	0·15	0·25	0·08
Water {hygroscopic	0·46	2·07	0·45	0·19			0·18		0·34	0·32
Water {combined	1·68		1·31	0·54	0·66	1·06	1·67	1·21	1·58	1·28
Organic matter	0 10		0·42	0·67	0·64	0·79	0·35	0·82	0·40	0·30
Ignited insoluble residue	19·48	19·22	13·50	9·60	14·50	27·58	10·83	17·27	8·63	13·60
	99·37		99·47	99·53	99·99	99·98	100·35	99·43	100·24	100·32
Ignited insoluble residue.										
Silica	12·45		7·75	6·83	9·46	19·90		11·60		
Alumina	5·58		4·64	2·42	4·20	6·09		4·29		
Sesquioxide of iron	0·60		0·55	0·43	-	0·60		0·45		
Lime	trace		0·14	traces	-	0·35		-		
Magnesia	0·07		0·08		0·20	-		0·30		
Potash	0·85		0·33	0·16	0·56	0·71		0·48		
	19·55		13·49	9·84	14·42	27·65		17·12		
Iron, total amount	30·40		34·75	40·27	35·48	28·55	40·12	32·44	36·77	37·32

TABLE VI.—ARGILLACEOUS IRON ORES FROM THE COAL MEASURES—*continued.*

	South Wales—*continued.*									
	59 a.	59 d.	E. R. 60.	A. D. 61.	A. D. 62.	E. R. 63.	A. D. 64.	E. R. (D.) 65.	E. R. (D.) 66.	E. R. (D.) 67.
Protoxide of iron	42·04	39·80	44·50	32·44	26·03	26·98	31·74	41·03	38·77	44·29
Sesquioxide of iron	-	-	-	-	-	-	-	-	-	-
Protoxide of manganese	0·87	1·17	0·73	0·80	1·09	0·49	1·06	0·55	1·30	1·13
Alumina	-	-	1·35	0·24	0·37	1·19	7·75	0·23	0·32	0·45
Lime	1·03	2·41	1·91	3·66	8·14	3·11	3·84	2·83	4·45	3·06
Magnesia	2 51	3·30	2·47	3·69	5·48	4·13	3·51	3·11	4·25	3·73
Potash	-	-	-	-	-	-	1·12	-	-	-
Silica	-	-	0·22	-	0·24	0·50	16·97	0·27	0·08	0·14
Carbonic acid	29·52	30·04	30·92	26·15	28·29	23·40	25·03	28·49	30·53	32·48
Phosphoric acid	0·90	1·02	0·23	0·28	0·17	0·35	0·35	0·70	0·46	0·42
Sulphuric acid	-	-	-	trace	trace	-	trace	-	-	-
Bisulphide of iron	0·06	0·05	0.11	0·30	0·69	0·52	0·48	-	-	-
Water { hygroscopic	0·36	0·54	- }	0·98	0·99	- }	undetermined	0·57	0·35	0·42
Water { combined	2·00	2·12	0 76 }			0·78 }		1·36	1·08	1·03
Organic matter	0·30	0·45	0·21	1·15	0·41	0·82	8·50	0·07	0·29	0·35
Ignited insoluble residue	20·87	19·40	15·73	30·01	27·35	36·51		20·33	17·95	13·01
	100·46	100·30	99·14	99·70	99·25	98·78	100·35	99·54	99·83	100·51
Ignited insoluble residue.										
Silica			10·59	20·04	18·32	27·41		13·08	13·47	7·77
Alumina			4·60	7·98	8·30	7·69		5·56	2·96	3·75
Sesquioxide of iron			0·50	0·76	0·56	0·73		0·41	0·40	0·41
Lime			0·18	0·27 }	traces	0·22	not analyzed separately	0·17	0·09	0·12
Magnesia			0·14	- }		0·42		0·25	0·15	0·19
Potash			0·79	0·81	0·82	1·18		0·86	0·87	0·74
			Soda 0·13			Soda 0·16			Sulphur 0·01	0·03
			16·93	29·86	28·00	37·81	26·16	20·33	17·95	13·01
Iron, total amount	33·20	31·45	34·96	26·01	20·95	21·49	24·90	32·18	30·43	34·72

Table VI.—ARGILLACEOUS IRON ORES FROM THE COAL MEASURES—*continued*.

	South Wales—*continued*.									
	E. R. (D.) 68.	E. R. (D.) 69.	A. D. 70.	A. D. 71.	72.	E. R. (D.) 73.	74.	C. T. 75.	76.	77.
						calcined				
Protoxide of iron	39·00	48·66	40·30	29·34	42·72	6·03	43·37	34·18	33·09	34·27
Sesquioxide of iron	-	-	-	-	-	54·03	4·10	-	0·64	3·37
Protoxide of manganese ...	0·50	1·21	1·03	0·73	0·46	1·22[2]	1·50[2]	1·82	1·21	1·47
Alumina	0·89	-	1·43	0·96	-	7·04	6·05	0·80	0·91	-
Lime	2·75	1·69	1·44	0·84	4·66	7·85	3·00	2·72	3·01	1·90
Magnesia	2·41	2·61	2·77	5·63	5·73	5·13	0·25	1·64	0·94	3·00
Potash	-	-	-	-	-	-	0·32	-	0·11	0·03
Silica	-	-	-	-	-	16·27	2·80	-	0·67	0·05
Carbonic acid	26 14	33·09	28·23	24·56	35·70	-	30·50	24·20	22·28	26·14
Phosphoric acid	1·28	0·58	0·88	0·14	0·49	1·21	traces	0·42	0·44	0·23
Sulphuric acid	-	-	trace	trace	-	-	1·56	-	0·60	0·15
Bisulphide of iron	-	0·07	0·09	0·08	trace	1·21[3]	-	not determined	0·45	0·29
Water { hygroscopic	0·79	0·25	0·74	1·00	0·26	0·08	0·27	2·00	0·37	0·90
Water { combined					1·54	-	0·81		1·19	1·23
Organic matter	1·60	11·08[1]	0·29	0·33	0·30	-	6·25	6·96	0·60	0·59
Ignited insoluble residue ...	24·44	1·21	22·48	35·73	8·23	-	-	25·20	33·41	27·29
	99·80	100·45	99·68	99·34	100·09	100·07	100·28	99·94	99·92	100·91
Ignited insoluble residue.										
Silica	not analyzed	not analyzed	14·43	24·98				not further analyzed	26·11	18·79
Alumina			6·47	9·75					7·30[4]	6·17[4]
Sesquioxide of iron			0·34	0·53					-	-
Lime			-	-					0·11	2·08[5]
Magnesia			0·17	0·20					0·07	0·04
Potash			0·82	1·00					0·31	0·19
	24·44	1·21	22·23	36·46				17·80	33·90	27·27
Iron, total amount	30·33	37·80	31·63	23·22	33·45	43·30	36·49	26·78	26·39	29·15

[1] Organic matter with a little water. [2] Estimated as Mn^3O^4. [3] Estimated as FeS. [4] With trace of iron. [5] This proportion of lime in the insoluble residue appears large.

TABLE VII.—ARGILLACEOUS IRON ORES FROM THE LIAS.

	Yorkshire.					
	A. D. 1.	2.	3.	4.	5. a.	5. b.
Protoxide of iron	39·92	43·02	39·00	33·85	35·25	-
Sesquioxide of iron	3·60	2·86	3·50	32·67	12·22	60·05
Protoxide of manganese	0·95	0·40	1·30	0·69	-	-
Alumina	7·86	5·87	7·46	3·15	14·10	15·45
Lime	7·44	5·14	7·44	2·86	2·38	1·15
Magnesia	3·82	5·21	3·82	1·59	3·95	0·72
Potash	0·27	-	-	trace	-	-
Silica	7·12	7·12	9·46	6·95	9·65	8·20
Carbonic acid	22·85	25·50	23·06	10·36	16·25	trace
Phosphoric acid	1·86	1·81	1·60	1·41	-	-
Sulphuric acid	trace	-	-	trace	trace	trace
Bisulphide of iron	0·11	-	-	0·03[2]	trace[2]	trace[2]
Water {hygroscopic	-	0·34	3·66	3·76	4·80	15·40
Water {combined	2·97	3·14				
Organic matter	trace	0·15	-	0·84	-	-
Ignited insoluble residue	1·64	0·05	-	-	-	-
	100·41	100·61	100·30	98·16	98·60	100·97
Ignited insoluble residue.		The insoluble residue was silica in the state of quartz. A trace of sulphide of zinc was found.			It is to be regretted that the phosphoric acid was not determined in these analyses.	
Silica	1·50					
Alumina	0·10[1]					
Sesquioxide of iron	-					
Lime	trace					
Magnesia	-					
Titanic acid	0·03	trace				
	1·63					
Iron, total amount	33·62	35·46	32·78	49·17	35·94	42·03

[1] With trace of sesquioxide of iron.

[2] Sulphur.

TABLE VII.—ARGILLACEOUS IRON ORES FROM THE LIAS—*continued.*

	YORKSHIRE—*continued.*							
	6.			7.			8.	
	a.	b.	c.	a.	b.	c.	a.	b.
Protoxide of iron	39·01	43·35	39·50	35·55	35·75	40·86	34·00	38·25
Sesquioxide of iron	3·55	1·20	1·55	1·70	1·80	4·25	7·00	5·80
Protoxide of manganese	-	-	-	-	-	-	-	-
Alumina	10·62	9·88	17·87	3·79	4·95	3·44	12·15	12·20
Lime	1·70	0·58	1·56	4·20	7·39	3·80	1·40	5·00
Magnesia	3·19	5·35	2·31	1·12	2·98	3·70	3·15	2·40
Potash	-	-	-	-	-	-	-	-
Silica	10·90	7·65	19·90	20·90	15·65	7·20	20·50	7·45
Carbonic acid	25·26 [3]	22·96 [3]	5·54 [3]	25·18 [3]	23·47 [3]	32·50	15·50	25·40 [3]
Phosphoric acid	2·08	3·87	2·50	2·66	5·05	0·96	2·55	0·50
Sulphuric acid	-	-	-	trace	0·07	0·30	trace	trace
Bisulphide of iron	trace [2]	0·09 [2]	0·13 [2]	trace [2]	trace [2]	1·60 [2]	0·06 [2]	trace [2]
Water {hygroscopic / combined}	3·69	5·07	9·14	4·90	4·89	1·45	5·00	3·00
Organic matter	-	-	-	-	-	-	-	-
Ignited insoluble residue	-	-	-	-	-	-	-	-
	100·00	100·00	100·00	100·00	102·00	100·06	101·31	100·00
Ignited insoluble residue.					The sum is given as 100 in the original. I have introduced this analysis because it presents the maximum of phosphoric acid. The author repeats the number 5·05 of this acid, so that it cannot be a printer's error.			
Silica								
Alumina								
Sesquioxide of iron								
Lime								
Magnesia								
Titanic acid								
Iron, total amount	32·83	34·54	28·73	28·84	27·45	34·75	31·36	33·81

[2] Sulphur.

[3] By loss.

TABLE VII.—ARGILLACEOUS IRON ORES FROM THE LIAS—*continued.*

	YORKSHIRE—*continued.*						
	9.		C. T. 10.	C. T. 11.			C. T. 12.
	a.	b.		a.	b.	c.	
Protoxide of iron	33·86	38·06	33·17	32·78	22·30	40·77	34·98
Sesquioxide of iron	0·47	2·60	-	-	-	-	-
Protoxide of manganese	0·96	0·74	0·50	0·45	0·50	0·67	0·48
Alumina	6·92	5·92	3·92	1·18	2·10	1·32	3·20
Lime	5·82	7·77	11·90	6·44	11·80	4·08	11·96
Magnesia	3·84	4·16	4·52	4·58	3·96	5·34	4·51
Potash	-	-	-	-	-	-	-
Silica	15·24	10·36	-	-	-	-	-
Carbonic acid	25·00	22·00	28·00	26·13	24·40	31·80	29·20
Phosphoric acid	1·40	1·07	0·48	0·19	0·30	0·06	1·30
Sulphuric acid	trace	trace	-	-	-	-	-
Bisulphide of iron	0·40 [2]	0·14 [2]	-	-	-	-	-
Water {hygroscopic / combined}	3·69	4·45	3·65	2·80	3·20	2·70	3·30
Organic matter	-	-	-	-	-	-	-
Ignited insoluble residue	-	-	13·22	24·10	30·96	12·36	10 04
	97·60	97·27	99·36	98·65	99·52	99·10	98·97
Ignited insoluble residue. Silica			9·42	18·12	23·10	8·80	8·00
			Other ingredients not determined.	Other ingredients not determined.	Other ingredients not determined.	Other ingredients not determined.	Other ingredients not determined.
Iron, total amount	26·66	31·42	25·80	25·50	17·34	31·71	27·21

[2] Sulphur.

OBSERVATIONS ON THE FOREGOING TABLES.

TABLE I.—MAGNETIC OXIDE OF IRON.

1. **Dartmoor,** *Devonshire.*—It was compact, black, sub-metallic in lustre, uneven and granular on fracture, and gave a black streak. There was disseminated through the ore a pale green mineral, which remained in the insoluble residue obtained by digestion with hydrochloric acid. Traces of bismuth, tin, and copper were detected in a solution of 900 grains of the ore.

TABLE II.—RED HÆMATITES.

1. **Cleator Moor,** WHITEHAVEN, *Cumberland.*—The ore is a compact red hæmatite; it contains cavities, lined with crystals of specular iron and quartz. A most minute trace of lead was detected in 400 grains of ore.

2. **Cleator Moor,** WHITEHAVEN, *Cumberland.*—The ore consisted of a compact and pulverulent unctuous red hæmatite. A trace of lead was detected in 500 grains of ore.

2*a*. From WHITEHAVEN.—This was analyzed at the Arsenal, Woolwich. Four analyses of pig-iron, reported to have been made from this ore, are given by Mr. Abel (p. 19 of his Report), and in all the proportion of silicon is large, the extremes being 3·02°/₀ and 2·63°/₀. And yet the ore is stated to have contained only 1°/₀ of silica. There is doubtless some mistake on this point. The ore may have been selected in the particular case; for it is well known that much of the ore from this locality abounds in silica.

3. **Gillbrow,** ULVERSTONE, *Lancashire.*—The ore is red hæmatite of the unctuous variety. It contains intermixed pieces of carbonate of lime, etc., which being coloured red cannot be seen until the specimen is washed. A minute quantity of a whitish metal, precipitable by sulphuretted hydrogen from the hydrochloric acid solution, was obtained from 500 grains; but it was too small in quantity to be identified.

4. **Lindale Moor,** near ULVERSTONE, *Lancashire.*—The sample prepared for analysis was selected from a large quantity of the ore, which consisted of fragments differing in degree of hardness; but the majority were of the hard compact variety of red hæmatite. A distinct trace of arsenic was detected in 1680 grains of ore.

4*a*. Compact red hæmatite from the **North Pit, Lindale Cote,** near ULVERSTONE, *Lancashire.*—The analysis was made by Mr. R. Smith, March, 1851. From 500 grains of the ore was obtained 0·024°/₀ of metallic oxide, which yielded a tin-white metal before the blow-pipe. No trace of nickel or cobalt was detected in 500 grains of the ore. All the preceding ores occur in the carboniferous limestone.

5. **Whitchurch,** near CARDIFF, *Glamorganshire.*—It is described as soft, dull, and greasy in lustre, soiling the fingers, and in structure oölitic, and sometimes pisolitic. No metal precipitable by sulphuretted hydrogen was detected in a solution of 300 grains of the ore. It was analyzed by Mr. W. Ratcliffe for the late Mr. E. Rogers of Abercarn. This occurs below or at the base of the carboniferous limestone.

TABLE III.—BROWN HÆMATITES.

1. From **Froghall,** near CHEADLE, *Staffordshire.*—It is a calciferous brown hæmatite, occurring in the lowest portion of the coal measures. It is compact, homogeneous, and brownish-red in colour. The lump contained a vein of calcareous spar. In a solution

of 450 grains of ore, sulphuretted hydrogen produced a slight precipitate, from which a minute trace of a whitish metal, too small to identify, was reduced. One specimen of this ore was nearly pure hydrated sesquioxide of iron.

2. **Black Brush Ore**, FOREST OF DEAN, *Gloucestershire*.—Minute traces of copper and lead were detected in a solution of 500 grains of the ore.

3. **Brandy Brush Ore**, FOREST OF DEAN.—It is a very impure and highly siliceous brown hæmatite. No metal precipitable by sulphuretted hydrogen was detected in a solution of 500 grains of the ore.

4. **Smith Ore**, FOREST OF DEAN.—It is a comparatively pure brown hæmatite. No metal precipitable by sulphuretted hydrogen was detected in a solution of 550 grains of the ore.

5. **Grey Vein**, FOREST OF DEAN.—It is a brown hæmatite containing a large proportion of carbonate of lime and magnesia. No metal precipitable by sulphuretted hydrogen was detected in a solution of 500 grains of the ore. Nos. 2, 3, 4, 5 occur in the carboniferous limestone.

6. From LLANTRISSANT, *Glamorganshire*.—From a remarkable deposit forming the base of the magnesian conglomerate, and resting on the carboniferous limestone.

7. Shipped at PENTUAN, *Cornwall*.—Obtained from lodes partly in the granite and partly in slaty rock near St. Austell.

8. From *Devonshire*. Precise locality not stated.—Distinct traces of arsenic, antimony, lead, and copper were detected in a solution of 500 grains of the ore. At Brixham, in Devonshire, there is a very large deposit of brown iron ore, which has long been extensively worked. The ore has been smelted in South Wales, and it has also been largely employed as a pigment. Close to Brixham is a mill, where it is prepared and ground with linseed oil into paint, which is specially recommended for painting ironwork.

9*a*. **Aluminous Ore**, BELFAST, *Ireland*.—Under this name I received specimens of the ore. It is in the state of conglomerate, consisting of small rounded siliceous pea-like pebbles cemented together. It is remarkable on account of the large proportion of alumina which it contains. Titanic acid was present, but not quantitatively determined.

9*b*. **Aluminous Ore**, BELFAST, *Ireland*.—Another sample analysed by Mr. E. Riley.

TABLE IV.—BROWN HÆMATITES, CHIEFLY FROM THE OÖLITE.

1. From WELLINGBOROUGH, *Northamptonshire*.—The ore consists essentially of earthy hydrated sesquioxide of iron. It is oölitic in structure, and ochre-brown in colour. The insoluble residue consisted almost entirely of siliceous oölitic concretions, but on dissolving these in potash a small amount of residue was left, containing quartzose sand, scales of mica, and minute spherical particles of magnetic oxide of iron. The ore contained numerous marine shells, and occurs in the Northampton Sand, which lies at the base of the Great Oölite, and is the geological equivalent of the Stonesfield Slate.[1] A trace of copper was detected in a solution of 660 grains of the ore.

The introduction of the Northamptonshire ore is only of recent date. Not long previous to the International Exhibition of 1851, Colonel (now General) Arbuthnot called upon me in Birmingham, where I then resided, and requested my opinion on a specimen of the ore which he left with me. I found it to contain a sensible quantity of sesquioxide of iron and a very large amount of siliceous sand. I made no quantitative examination of it; and, certainly, the specimen in question did not prepossess me in its favour. However, I referred the Colonel to my friend, Mr. S. H. Blackwell, of

[1] This is stated on the authority of my colleague Professor A. C. Ramsay.

Dudley, who visited the locality of the ore in order to examine it *in situ*. He obtained samples much richer in iron than that which was placed in my hands. He prosecuted inquiries on the subject with his usual energy, and the result has been the discovery of an extensive deposit of ore, which has since been smelted in large quantity in South Staffordshire, Derbyshire, and South Wales.

2. From Wellingborough, *Northamptonshire*.—It was similar to the last, but ochre-yellow in colour. The insoluble residue for the most part consisted of siliceous oölitic concretions, and contained also quartzose sand, mica, and small black particles of magnetic oxide of iron.

3. From Wellingborough, *Northamptonshire*.—It was in all respects similar to the last. A minute trace of a malleable metal, apparently lead, was detected in the ore. Nearly the whole of the silica, it will be perceived, existed in the form of oölitic concretions. The insoluble residue contained quartzose sand, mica, and small particles of magnetic oxide of iron.

4. From Hardingstone, a village near *Northampton*.

5. From the **East End Iron Works**, Wellingborough, *Northamptonshire*.—The ore was ochre-brown in colour. The sample analyzed was an average of three specimens. No appreciable amount of sulphur was found in the ore.

6. From the **Heyford Iron Works**, near Weedon, *Northamptonshire*.—The ore was similar in appearance to the preceding. The sample analyzed was an average of two specimens. No appreciable amount of sulphur was found in the ore.

7 and 8.—These analyses are of the inner and outer portions respectively of a lump of Northamptonshire iron ore. The inner portion, it will be observed, consists for the most part of carbonate of protoxide of iron, and the outer portion of hydrated sesquioxide, the latter having been clearly derived from the former by atmospheric action. No metal precipitable by sulphuretted hydrogen was detected in a solution of 880 grains of the ore, No. 7. On the contrary, extremely minute traces of copper and lead were detected in a solution of 744 grains of the ore, so that these metals appear to have been communicated to the ore by water from without.

9. From Banbury, *Oxfordshire*.—This cannot be regarded as an iron ore, properly so called. Of the 7·36 of insoluble residue 5·02 dissolved in dilute potash.

10. From Woodstock, *Oxfordshire*, on the estate of the Duke of Marlborough.—The analysis is of an average sample prepared from several specimens. The ore much resembles in appearance some of the yellowish-brown varieties of Northamptonshire ore. It occurs in the Marlstone between the Upper and Lower Lias.

11. From Brigg, *Lincolnshire*.—It much resembles the preceding. It occurs as a superficial deposit, but I cannot ascertain that its precise geological position has been satisfactorily determined.

12. From *Dorsetshire*, on the estate of the Earl of Shaftesbury.—It much resembles the preceding.

13. From Seend, in *Wiltshire*.—The specimen analyzed much resembled the preceding, and was from the out-crop, where it had been exposed to atmospheric oxidation. It is a highly siliceous earthy hydrated sesquioxide of iron. It occurs in the Lower Greensand.

Table V.—SPATHIC CARBONATES.

1. **West Level, Tow Law Iron Works**, Weardale, *Durham*.—The ore consists essentially of hydrated sesquioxide of iron and carbonate of protoxide; and is evidently the result of the incomplete decomposition of spathic carbonate by the conjoint action of air and moisture. Fluor-spar and galena occur in association with this ore. A small quantity of the spar was attached to the lump of ore from which the portion for

analysis was taken, but it was carefully separated and put aside. A trace of lead was detected in 400 grains of ore.

2. Rispey Vein, ROOKHOPE, a lateral valley opening into Weardale.—The ore is spathic carbonate. When a piece of it is digested in hydrochloric acid until everything soluble is removed, there remains a siliceous skeleton of the shape and size of the piece originally. No metal precipitable by sulphuretted hydrogen was found in a solution of 1000 grains of the ore.

3. Weardale, DURHAM.—Spathic carbonate, of a light-brown colour. Transparent, colourless particles of quartz are diffused through the mass, which may be distinctly recognised. It contains a little copper: 1000 grains of ore gave 0·26 of protoxide (CuO).

4. Weardale, DURHAM.—It is essentially hydrated sesquioxide of iron, resulting from the decomposition of spathic carbonate. Its colour is chocolate-brown. It contained a trace of copper. All the preceding ores occur in the Carboniferous Limestone.

5. Brendon Hills, *Somersetshire.*—It consisted essentially of crystallized carbonate of protoxide of iron, with thin laminæ of unctuous red hæmatite irregularly disseminated through the mass. The outer surface was discoloured by peroxidation, and the sample analyzed was, therefore, taken from the interior. A minute trace of phosphoric acid, but no sulphur, was found in 120 grains of the ore. No metal precipitable by sulphuretted hydrogen was detected in a solution of 600 grains of the ore. The composition of the insoluble residue was calculated from the results of an analysis of 1·725 grains of such residue from 600 grains of ore. It has been extensively worked during the last few years by the Ebbw Vale Iron Company. My colleague, Mr. Warington Smyth, informs me that he has lately visited the mines, and was much struck with the beautiful masses, which were largely crystalline and resembled the pure mineral. It occurs in the Devonian series.

6. Exmoor, *Devonshire.*—It consisted essentially of crystallized carbonate of lime and carbonates of protoxide of iron and manganese. In the ore were observed particles of quartz, a green micaceous mineral insoluble in hydrochloric acid (chlorite?), and small particles of iron pyrites. No metal precipitable by sulphuretted hydrogen was detected in a solution of 480 grains of the ore. The proportion of iron is so small, that the ore would be properly designated ferriferous limestone. Spathic ore, unchanged and in various degrees of conversion into hydrated sesquioxide, is found at Exmoor, the property of Mr. Knight. It has recently been worked to some extent, and shipped to South Wales. I have seen stacks of excellent ore from this locality lying at Lynmouth for shipment. The cost of carriage to the sea is at present an insuperable objection to the development of Mr. Knight's mines, but I am informed that it is proposed to construct a railway to Minehead expressly for the conveyance of this ore.

TABLE VI.—ARGILLACEOUS IRON ORES FROM THE COAL MEASURES.

1. White Bed Mine, BRIERLEY, *Yorkshire.*—It consists of the following series of measures:—Top Flats, Low Flats, White Balls, Middle Balls, and Low Measure. The sample analyzed was prepared from equal weights of these varieties. There was a vein of iron-pyrites in the White Balls. A distinct trace of copper was detected in a solution of 500 grains of the ore.

2. Black Bed Mine, LOW MOOR, *Yorkshire.*—It consists of the following measures:—Top Balls, Flat Stone, Middle Balls, Rough Measure, Low Measure, Basset Stone. The sample analyzed was prepared from equal weights of these varieties. The Rough Measure contained iron pyrites in the form of exceedingly fine films taking the outline of shells. No metal, precipitable by sulphuretted hydrogen, was found in a solution of 600 grains of the ore.

2*a*. **Black Bed Mine**, supplied by Messrs. Harding and Co. of the Beeston Manor Iron-Works, near Leeds, to the Arsenal at Woolwich for analysis. Cast-Iron Experiments (*Blue Book*), p. 189. It was reported to be the same as treated at the Low Moor Iron-works.

3. **Thorncliffe**, or **Old Black Mine**, PARKGATE, *Yorkshire*.—It consists of two measures—Balls and Holing Measure. The sample analyzed was prepared from equal weights of these varieties. The first was seamed with numerous cracks of contraction, filled with carbonate of lime, carbonate of iron, etc.; the second contained impressions of *stigmaria* rootlets. No metal, precipitable by sulphuretted hydrogen, was found in a solution of 500 grains of the ore.

4. **Thorncliffe White Mine**, PARKGATE, *Yorkshire*.—It consists of three measures—Flats, Balls, and Holing Measure. The sample analyzed was prepared from equal weights of these varieties. In the second were small veins of sulphate of baryta and carbonate of lime, with a trace of iron pyrites. A trace of sulphate of baryta was found in the analysis. A minute trace of copper was detected in a solution of 450 grains of the ore.

5. **Black or Clay Wood Mine**, PARKGATE, *Yorkshire*.—Small particles of iron pyrites were sparingly diffused through the ore. Traces of lead and copper were detected in a solution of 680 grains of the ore.

6. **Swallow Wood Rake**, STANTON, *Derbyshire*.—The sample analyzed was prepared from equal weights of three specimens, which were not distinguished from each other by specific names. No metal, precipitable by sulphuretted hydrogen, was detected in a solution of 560 grains of ore.

7. **Brown Rake**, BUTTERLEY, *Derbyshire*.—It consists of three measures, Balls, Top Measure, and Bottom Measure. The sample analyzed was prepared from equal weights of the first two varieties. A trace of a reddish metal, too small to examine, was detected in a solution of 1200 grains of the ore.

8. **Brown Rake**, BUTTERLEY, *Derbyshire*.—The sample analyzed was from the Bottom Measure referred to in the preceding description of No. 7. Distinct traces of lead and copper were detected in a solution of 600 grains of the ore.

9. **Black Rake**, BUTTERLEY, *Derbyshire*.—It consists of two measures, Top Measure and Bottom Measure. The sample analyzed was prepared from equal weights of these varieties. The second contained thin films of iron pyrites disposed in the form of shells. Distinct traces of copper and lead were detected in a solution of 700 grains of the ore.

10. **Dog-tooth Rake**, STAVELEY, *Derbyshire*.—It consists of the following measures:—White Measure, Sugar-Plum Measure, Marble Measure, Balls, and Snail Horn. This rake is called Wallis' Rake at Butterley, south of which it does not prove. The sample analyzed was prepared from equal weights of the first, second, and fourth of these varieties. The second contained a few shells irregularly diffused. A minute trace of copper was detected in a solution of 630 grains of the ore.

11. **Dog-tooth Rake**, STAVELEY, *Derbyshire*.—The sample analyzed was prepared from equal weights of the third and last varieties enumerated under No. 10. Both contained abundance of shells. A minute trace of a white metal, too small to examine, was detected in a solution of 460 grains of the ore.

12. **Honeycroft Rake**, STANTON, *Derbyshire*.—It consists of the following measures:—Chitters, Tufty Balls, Barren Beet, Grindstone Measure, Grinder's Wife, Big Balls, Bottom Flats, and Brick Measure. The sample analyzed was prepared from equal weights of these several varieties. In the second were cracks of contraction filled with carbonate of iron, lime, etc. (brown-spar); it also contained some shells and zinc-blende. A minute trace of copper was detected in a solution of 480 grains of the ore.

13. Civilly Rake, STANTON, *Derbyshire.*—It consists of the following measures:— Rachell Measure, Chance Balls, Bottom Measure, Chitters, and Coal Measure. The sample analyzed was prepared from equal weights of all these varieties. In the second were internal cracks filled with pink sulphate of baryta, a little carbonate of lime, and zinc blende. A trace of sulphate of baryta was found in the analysis, and a minute trace of copper was detected in a solution of 500 grains of the ore.

14. Dale Moor Rake, STANTON, *Derbyshire.*—It consists of the following measures:— Clunch Balls, Roof Measure Balls, Roof Measure, Over Bottom, and Bottom Balls. The sample analyzed was prepared from equal weights of all these varieties. The first contained impressions of vegetable remains, including many *stigmaria* rootlets, and fish scales: perfect fossil fishes occur in this ironstone. These animal remains sufficiently account for the comparatively large proportion of phosphoric acid set down in the analysis. Zinc-blende and a distinct trace of copper were found in the ore.

15. Brooch Ironstone, CORNGREAVES, *Staffordshire.*—It contained small tubular cavities filled with white clay, in which was zinc-blende. Besides zinc in the form of blende, a trace of white metal, precipitable by sulphuretted hydrogen, but too small to identify, was detected in a solution of 460 grains of the ore. The so-called Brooch Brazil is generally found in the centre of the Brooch Coal at Tividale, and occasionally at West Bromwich. It occurs irregularly in pieces varying in size from a walnut to lumps 12 inches long and 4 inches or 5 inches thick, and when drawn resembles the Brazil in the ten-yard coal. A specimen of this stone, which I took from the Hange Colliery, Tividale, contained 35·08 % of iron, or somewhat more than the Corngreaves stone.

16. Pins, DUDLEY, *Staffordshire.*[1]—A trace of whitish metal precipitable by sulphuretted hydrogen was detected in a solution of 600 grains of ore.

17. Penny Earth, DUDLEY, *Staffordshire.*—No metal precipitable by sulphuretted hydrogen was detected in a solution of 600 grains of ore.

18. Grains, DUDLEY, *Staffordshire.*—No metal precipitable by sulphuretted hydrogen was detected in a solution of 900 grains of ore.

18*a* and 18*b*. Grains, supplied by Messrs. Grazebrook, of the Netherton Iron-Works, near Dudley, to the Arsenal at Woolwich for analysis. Cast-iron Experiments (*Blue-Book*), p. 78.

18*c*. Grains, from BELL FARM, supplied by Messrs. Badger and Co., Old Hill Furnace, Dudley, to the Arsenal at Woolwich for analysis. Op. cit. p. 96.

19. Gubbin Ironstone (Gubbin), DUDLEY, *Staffordshire.*—It contained thin veins of white and reddish brown matter, in which zinc-blende, galena, and copper-pyrites were visible. No metal precipitable by sulphuretted hydrogen was detected in a solution of 500 grains of the ore.

19*a*. Gubbin, supplied by Messrs. Grazebrook, of the Netherton Iron-Works, near Dudley, to the Arsenal at Woolwich for analysis. Op. cit. p. 78.

19*b*. Gubbin, from BELL FARM, supplied by Messrs. Badger and Co., Old Hill Furnace, Dudley, to the Arsenal at Woolwich for analysis.

20. Gubbin Ironstone (Cannock), DUDLEY, *Staffordshire.*—It contained thin veins of greyish-white matter with blende. No metal precipitable by sulphuretted hydrogen was detected in a solution of 500 grains of the ore.

21. Gubbin Ironstone (Rubble), DUDLEY, *Staffordshire.*—No metal precipitable by sulphuretted hydrogen was detected in a solution of 500 grains of the ore.

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[1] Dudley is in an isolated piece of Worcestershire in South Staffordshire; and I have, therefore, described it as in the last-named county, as is certainly the case in a geological point of view.

22. Whitestone Bind, DUDLEY, *Staffordshire.*—In the ore was a vein of carbonate of lime containing small crystals of galena. A trace of lead was found in a solution of 300 grains of the ore.

The rock overlying the whitestone in some localities has been examined, and found to contain a much larger proportion of iron than its appearance would indicate. Mr. S. H. Blackwell has communicated to me the following incomplete analyses of the rock separating the two bands of bottom whitestone at Bilston, which he has largely and very advantageously smelted in conjunction with cinders:—

Protoxide of iron	31·00	31·23
Oxide of manganese	2·50	0·30
Alumina	5·80	5·15
Lime	8·30	10·41
Magnesia	2·50	6·00
Silica	11·50	11·50
Phosphoric acid	0·31	none.
Sulphuric acid	1·13	trace.

Two specimens of the rock overlying the whitestone which I got myself at the Oak Colliery, West Bromwich, have been assayed by Mr. Smith, in my laboratory, and yielded respectively 26°/₀ and 30°/₀ of iron. I am informed that it is used at Bilston for making Roman cement.

22a. Binds, supplied by Messrs. Grazebrook and Co., Netherton Iron-Works, near Dudley, to the Arsenal at Woolwich for analysis. Op. cit. p. 78.

23. Bottom Whitestone, DUDLEY, *Staffordshire.*—It was irregularly seamed with numerous small veins of carbonate of lime; and it also contained a small quantity of white clay. No metal precipitable by sulphuretted hydrogen was detected in a solution of 300 grains of the ore.

23a and **23b. Whitestone**, supplied by Messrs. Grazebrook and Co., Netherton Iron-Works, near Dudley, to the Arsenal at Woolwich for analysis. p. 78.

23c. Whitestone, WEST BROMWICH, *Staffordshire*, supplied by Messrs. Badger and Co., Old Hill Furnace, Dudley, to the Arsenal at Woolwich for analysis. Op. cit. p. 96.

24. Cakes or **Bluestone**, DUDLEY, *Staffordshire.*—It contained veins of carbonate of lime. No metal precipitable by sulphuretted hydrogen was detected in a solution of 200 grains of the ore.

25. Cakes or **Bluestone**, DUDLEY, *Staffordshire.*—No metal precipitable by sulphuretted hydrogen was detected in a solution of 600 grains of the ore.

26. Fire-Clay Balls, DUDLEY, *Staffordshire.*—It is a coarse-grained crystalline carbonate of protoxide of iron, varying in colour from light to dark brown. No metal precipitable by sulphuretted hydrogen was detected in a solution of 1140 grains of the ore.

27. Fire-Clay Balls, DUDLEY, *Staffordshire.*—It is a fine-grained greyish-brown crystalline carbonate of protoxide of iron. It contained veins of calc-spar, and white pulverulent silicate of alumina, in which were small white crystalline globular concretions, consisting of carbonate of lime and magnesia. No metal precipitable by sulphuretted hydrogen was detected in a solution of 750 grains of the ore.

28. Poor Robin's, BUNKER'S HILL, *Staffordshire.*—A trace of copper was detected in the solution of 1030 grains of the ore.

29. Rough Hill Whitestone (good sample), DARLASTON, *Staffordshire.*

30. Rough Hill Whitestone (bad sample), DARLASTON, *Staffordshire.*—The ore contained shale. A trace of copper was detected in the solution of 500 grains of the ore.

31. Rough Hill Whitestone, Rough Hay Colliery, Darlaston, *Staffordshire.*—The ore contained sesquioxide of iron, copper pyrites, and veins of silicate of alumina (white clay). The presence of copper was distinctly proved in a solution of 800 grains of the ore.

32. Whitestone, Rough Hay Colliery, Darlaston, *Staffordshire.*—Microscopic crystals of copper pyrites were very sparingly diffused through the ore. The presence of copper was distinctly proved in a solution of 500 grains of the ore.

33. Gubbin and Balls, Bunker's Hill Colliery, *Staffordshire.*—The ore was seamed with white pulverulent silicate of alumina, and grey crystalline carbonate of lime. A minute trace of lead was detected in a solution of 740 grains of the ore.

34. Gubbin and Balls, Bunker's Hill Colliery, *Staffordshire.*—The ore contained veins of greyish-white pulverulent silicate of alumina and traces of galena. No metal precipitable by sulphuretted hydrogen was detected in a solution of 750 grains of the ore.

34a. Balls, Bilston, *Staffordshire,* supplied by Messrs. Badger and Co., Old Hill Furnace, Dudley, to the Arsenal at Woolwich for analysis. Op. cit. p 96.

35. Gubbin and Balls (Balls), Rough Hay Colliery, Darlaston, *Staffordshire.*—The ore was seamed with veins of greyish-white silicate of alumina, in which were minute crystals of zinc-blende, iron-pyrites, and copper-pyrites. The presence of copper was distinctly proved in a solution of 800 grains of the ore.

36. Gubbin and Balls (Gubbin), Rough Hay Colliery, Darlaston, *Staffordshire.*—The ore contained white pulverulent silicate of alumina, a large quantity of zinc-blende, and minute crystals of iron-pyrites. No metal precipitable by sulphuretted hydrogen was detected in a solution of 400 grains of the ore.

37. Blue Flats, Rough Hay Colliery, Darlaston, *Staffordshire.*—The ore was irregularly seamed with veins of calc-spar, with greyish-white and reddish-brown silicate of alumina, containing minute crystals of iron-pyrites. No metal precipitable by sulphuretted hydrogen was detected in a solution of 400 grains of the ore. The Blue Flats Ironstone has been one of the most productive in South Staffordshire. It is one of the deepest measures, and does not extend far over the Staffordshire coal-field. It chiefly occurs in the district of Wolverhampton.

38. Silver Threads, Rough Hay Colliery, Darlaston, *Staffordshire.*—The ore was irregularly seamed with numerous veins of calc-spar, coated with drab-coloured ferruginous matter. No metal precipitable by sulphuretted hydrogen was detected in a solution of 600 grains of the ore.

39. Diamonds, Rough Hay Colliery, Darlaston, *Staffordshire.*—The ore contained veins of calc-spar and silicate of alumina, in which galena, zinc-blende, copper-pyrites, and iron-pyrites were observed. Traces of lead and copper were detected in the solution of 800 grains of the ore.

40. Diamonds, Darlaston, *Staffordshire.*—The ore was seamed with a white powder and carbonate of lime, in which minute crystals of zinc-blende were observed. No metal precipitable by sulphuretted hydrogen was detected in a solution of 740 grains of the ore.

40a. White substance occurring in Diamonds (Nos. 39 and 40). It was weighed for analysis after drying over sulphuric acid. It is a hydrated silicate of alumina.

41. Brown Stone, Bloxwich, *Staffordshire.*—The ore contained veins of white pulverulent and grey substances, in which were traces of galena and copper-pyrites. No metal precipitable by sulphuretted hydrogen was detected in a solution of 550 grains of the ore. In the collection of British Iron Ores exhibited by Mr. S. H. Blackwell at the International Exhibition of 1851, there were two varieties of ironstone

labelled "Bloxwich." That of which the analysis is given above had the usual light-brown colour of many argillaceous ores; but the other was a "Black-band ironstone," of which no complete analysis has been made in my laboratory. It contained 25·34°/$_0$ of iron, and not less than 30·17°/$_0$ of organic matter. It exists only in the northern portion of the South Staffordshire coal field, north of the Bentley Fault. Its true position is between the Heathen Coal and white ironstone. There is also an ironstone termed "Brownstone," which occasionally occurs near Dudley, underneath the Gubbin Rubble, and this we have neither analyzed nor examined chemically.

42. **Red Shag**, from SHELTON COLLIERY, HANLEY, and APEDALE, NEWCASTLE-UNDER-LYNE, *Staffordshire.*—The sample for analysis was prepared in the usual manner with specimens from each of the above localities. This ore contains sufficient bituminous matter to constitute it a true black-band ironstone. No metal precipitable by sulphuretted hydrogen was detected in a solution of 780 grains of the ore.

43. **Gutter Mine**, SHELTON COLLIERY, *Staffordshire.*—The ore consisted of alternate layers of clay ironstone, coaly matter, and fossil shells. A small quantity of zinc-blende was also found in it. The sample analyzed was prepared by taking a section of the specimen across the component layers. Distinct traces of lead and copper were detected in a solution of 760 grains of the ore.

44. **Red Mine**, APEDALE, NEWCASTLE-UNDER-LYNE, *Staffordshire.*—It consists of thin layers of various shades of dark brown, and may be properly described as a black-band ironstone. Minute crystals of galena and zinc-blende were very sparingly diffused through the ore. No metal precipitable by sulphuretted hydrogen was detected in a solution of 680 grains of the ore. This ore in a calcined state has long been largely sent into South Staffordshire.

45. **Bassey Mine**, from FOLEY and SHELTON COLLIERIES, and from APEDALE, NEWCASTLE-UNDER-LYNE, *Staffordshire.*—The sample analyzed was prepared in the usual manner with specimens from each of the above localities. In the specimen from the last-named locality minute crystals of zinc-blende were observed. No metal precipitable by sulphuretted hydrogen was detected in a solution of 1180 grains of the ore.

46. **Cannel Mine**, APEDALE, NEWCASTLE-UNDER-LYNE, *Staffordshire.*—The ore was intersected by very thin veins of carbonate of lime. A minute trace of copper was detected in a solution of 750 grains of the ore.

47. **Pennystone**, SHELTON COLLIERY, *Staffordshire.*—It contained crystals of zinc-blende. No metal precipitable by sulphuretted hydrogen was detected in a solution of 765 grains of the ore.

48. **Deep Mine**, from FOLEY and SHELTON COLLIERIES, and from APEDALE, *Staffordshire.*—The sample analyzed was prepared in the usual manner with specimens from each of the above localities. The ore from the second locality contained minute crystals of zinc-blende and copper-pyrites. In the pieces of ore from the other two localities were cracks containing greyish-white hydrated silicate of alumina and carbonate of lime. Extremely minute traces of copper and lead were detected in a solution of 1100 grains of the ore.

49. **Chalky Mine**, from FOLEY and SHELTON COLLIERIES, and from APEDALE, *Staffordshire.*—The sample analyzed was prepared in the usual manner with specimens from each of the above localities. In the first variety minute crystals of zinc-blende and iron-pyrites were observed; the second contained white and yellowish grey thin crystalline veins, chiefly of carbonate of lime; and in the third were cracks filled with white pulverulent hydrated silicate of alumina, coloured in some places with sesquioxide of iron, and zinc-blende was also present. Extremely minute traces of copper and lead were detected in a solution of 1093 grains of the ore. Specimens

from the same bed of ironstone in different localities appeared to vary sensibly; and instead of analyzing an average sample of these, it would, probably, have been better to have operated upon a selected specimen from one locality. The selection, however, of the particular specimens for analysis was entrusted to Mr. Kenyon Blackwell, who considered that the results obtained from an analysis of an average sample of the same bed in different localities would be most useful to ironmasters.

49a. Chalky Mine, from the GOLDENDALE IRON-WORKS, near STOKE-UPON-TRENT, *Staffordshire.*—It was analyzed at the Arsenal (Cast-iron Experiments, p. 66).

49b. Ironstone from BEDWORTH, *Warwickshire.*—This ore has been extensively smelted in South Staffordshire, and is considered of excellent quality. The analysis was made by myself many years ago.

50. Black Flats, *Shropshire.*—A very small quantity of the iron existed in the state of sesquioxide. No metal precipitable by sulphuretted hydrogen was detected in a solution of 820 grains of the ore.

51. Blue Flats, DONNINGTON WOOD, *Shropshire.*—The sample analyzed was prepared from two specimens, in one of which zinc-blende was observed and in the other a few very thin films of iron-pyrites. Sulphide of zinc and a distinct trace of copper were found in the ore.

52. White Flats, DONNINGTON WOOD, *Shropshire.*—A minute trace of a reddish metal too small to identify, though probably copper, was detected in a solution of 480 grains of the ore.

53. Pennystone, DONNINGTON WOOD, *Shropshire.*—The specimen operated upon was nodular, and presented veins of contraction filled with sulphate of baryta, partly in white crystals and partly in a pulverulent state. Small particles of iron-pyrites were sparingly distributed over the surface of the crystals of sulphate of baryta and in the internal cavities of the ironstone. These crystals were analyzed, and proved to have the following composition :—

	1.	2.
Sulphate of baryta	98·52	98·40
Silica	0·86	
Alumina	0·20	
Sesquioxide of iron	trace.	
	99·58	

The white powder was also found to consist mainly of sulphate of baryta; but as it was difficult to free it from small particles of the ironstone matrix, the constituents of the ore made their appearance in the course of the analysis more prominently than in the case of the crystals.

54. Pennystone, DONNINGTON WOOD, *Shropshire.*—A minute trace of a white malleable metal, too small in quantity to identify, was detected in a solution of 300 grains of the ore.

55. Pennystone, MADELEY COURT, *Shropshire.*—It contained thin veins filled with white pulverulent silicate of alumina, in which some crystals of iron-pyrites were observed. A very small quantity of the iron existed in the state of sesquioxide. No metal precipitable by sulphuretted hydrogen was detected in a solution of 445 grains of the ore.

56. Crawstone, MADELEY WOOD, *Shropshire.*—The ore was traversed by veins of white calcareous spar, containing a small quantity of carbonate of iron. It did not contain an appreciable amount of iron in the state of sesquioxide. A trace of lead was present in the state of galena.

57. Spotted Vein Mine, BLAENAVON, *Monmouthshire.*—Minute traces of copper and lead were detected in the solution of 905 grains of the ore.

58. Three-Quarter Balls, BLAENAVON, *Monmouthshire*.—Minute traces of copper and lead were detected in the solution of 870 grains of the ore.

58a. It was analyzed at the Arsenal under the name of Ball Mine (Op. cit. p. 148).

59. Black Pins, BLAENAVON, *Monmouthshire*.—A minute trace of copper was detected in the solution of 900 grains of the ore.

59a. Black Pins, from the BLAENAVON IRON-WORKS.—It was analyzed at the Arsenal (Op. cit. p. 148).

59b. Pwll Llacca, from the BLAENAVON IRON-WORKS.

59c. Bottom Vein, from the BLAENAVON IRON-WORKS.—It was analyzed at the Arsenal (Op. cit. p. 148).

59d. Grey Vein, from the BLAENAVON IRON-WORKS (Op. cit. p. 148).

60. Spotted Vein Mine (Balls), PONTYPOOL, *Monmouthshire*.—The ore was seamed with tolerably thick veins of brown spar (carbonate of protoxide of iron and lime). A distinct trace of copper was detected in a solution of 200 grains of the ore.

61. Meadow Vein Mine, PONTYPOOL, *Monmouthshire*.—Extremely minute traces of copper and lead were detected in a solution of 740 grains of the ore.

62. Three Cakes, Meadow Vein Mine, PONTYPOOL, *Monmouthshire*.—A trace of copper was detected in a solution of 600 grains of the ore.

63. Black Pin Mine (Middle Pin), PONTYPOOL, *Monmouthshire*.—A distinct trace of copper was detected in a solution of 234 grains of the ore.

64. Black Band, PONTYPOOL, *Monmouthshire*.—Traces of silver and copper were found in a solution of 600 grains of the ore. Mr. Dick detected the silver by wet analysis, without having the least suspicion of its presence; but I am informed that this fact was previously known, and the ore is stated to contain about ½ oz. of silver to the ton.

65. Rosser Vein Mine, DOWLAIS, MERTHYR-TYDVIL, *Glamorganshire*.—This and the following analyses, numbered 65, 66, 67, 68, 69, were made by Mr. Edward Riley at the Dowlais Iron-Works.

66. Little Blue Vein, DOWLAIS, MERTHYR-TYDVIL, *Glamorganshire*.—The sample analyzed was prepared from a mixture of equal weights of the four beds composing this vein. Traces of copper were detected in a solution of 500 grains of the ore.

67. Lumpy Vein, DOWLAIS, MERTHYR-TYDVIL, *Glamorganshire*.—The sample analyzed was prepared from a mixture of equal weights of the three beds composing this vein.

68. Gŵr-Hyd Mine, DOWLAIS, MERTHYR-TYDVIL, *Glamorganshire*.

69. Black Band, DOWLAIS, MERTHYR-TYDVIL, *Glamorganshire*.

70. Sulphury Mine, CWM AVON, *Glamorganshire*.—This ore is in high repute. It occurs in three courses, averaging about 7 inches in thickness together. The sample analyzed was prepared from equal weights of the three kinds. A trace of copper was detected in a solution of 800 grains of the ore.

71. White Pins, sometimes called **Coedfalda Mine**, YSTALYFERA, *Glamorganshire*.—This measure consists of two courses, balls and pins. The sample analyzed was prepared with equal weights of each. A trace of lead was detected in a solution of 910 grains of the ore.

72. Cheese Mine, from the YSTALYFERA IRON-WORKS.—It was in nodules, dark grey in colour, and intersected by numerous veins of calcareous brown spar, in which a few crystals of quartz were observed. It was analyzed at the Arsenal (Op. cit. p. 136).

73. Worthington's Black Band, LANCAICH, near QUAKER'S YARD, *Glamorganshire*.—The analysis was made at the Dowlais Iron-Works by Mr. E. Riley.

74. **Black Band,** ABERCARN, *Monmouthshire.*—Its colour was brownish-grey, and it contained laminæ of coal and films of iron-pyrites in some of the fissures. It was analyzed by Mr. W. Ratcliffe for the late Mr. E. Rogers, of Abercarn.

75. **Black Band,** GWENDRAETH VALLEY, near LLANELLY, *Glamorganshire.*

76. **Catshole Ironstone,** SAUNDERSFOOT, *Pembrokeshire.*—Crystals of calc-spar and iron-pyrites were observed in it. No metal precipitable by sulphuretted hydrogen was detected in a solution of 150 grains of the ore. It was analyzed by Mr. W. Ratcliffe, for the late Mr. E. Rogers, of Abercarn.

77. **Kilvelgy Ironstone,** SAUNDERSFOOT, *Pembrokeshire.*—Iron-pyrites was observed in some of the fissures. No metal precipitable by sulphuretted hydrogen was detected in a solution of 150 grains of the ore. It was analyzed by Mr. W. Ratcliffe, for the late Mr. E. Rogers, of Abercarn.

TABLE VII.—ARGILLACEOUS IRON ORES FROM THE LIAS.

1. From CLEVELAND, *Yorkshire.*—It is essentially an earthy carbonate of protoxide of iron, of a greenish-grey colour. Throughout the ore were irregularly diffused small oölitic concretions. The large amount of silica soluble in the hydrochloric acid solution is remarkable; and a considerable proportion of this seems to be in combination with mixed proto- and sesqui- oxides of iron, forming what is usually designated green silicate of iron. When a piece of the ore is digested in hydrochloric acid till everything soluble is removed, a residue is obtained of the original form of the piece of ore. It is extremely light, and crumbles to powder unless very carefully handled; by the action of dilute caustic potash upon it, the siliceous skeletons of the oölitic concretions which it contains dissolve completely, and insoluble matter is left, which, on levigation with water, yields a small number of microscopic crystalline particles; some of these are white and consist of quartz, while others are black and are composed chiefly of titanic acid. The latter, which are acutely pyramidal, have been examined by my friend, Professor Miller, of Cambridge, who succeeded in measuring some of the angles, which were found to correspond to similar angles in *anatase.* No metal precipitable by sulphuretted hydrogen was detected in a solution of about 1200 grains of the ore. Of the 1·64 of insoluble residue 0·98 dissolved in dilute caustic potash.

2. From **South Bank Furnaces,** MIDDLESBRO'-ON-TEES, *Yorkshire.*—It was essentially the same kind of ore as the preceding. It was dull green in colour, and contained an abundance of small oölitic concretions, a few belemnites, and other fossil remains. Small crystals of quartz, zinc-blende, and what appeared to be titanite, were found in the ore examined. No appreciable amount of sulphur was detected, nor any metal precipitable by sulphuretted hydrogen.

3. From the **Belmont Mines,** STOCKTON IRON-WORKS, CLEVELAND, *Yorkshire.*—The ore operated on was more dense and compact than, but in other respects similar to, Nos. 2 and 3.

4. **Rosedale Ironstone,** from ROSEDALE ABBEY, *Yorkshire.*—It is blue-black in colour. It is magnetic and polar. The analysis was by Mr. John Pattinson, chemist to the Clarence Iron-Works, and is extracted from Mr. Crowder's paper on the Rosedale, Whitby, and Cleveland Ironstones in the Edinburgh New Philosophical Journal, 5, p. 40, 1857.

5. **Rosedale Ironstone,** from ROSEDALE ABBEY, *Yorkshire.*—It is similar to the preceding, except in colour, which is light blue-grey; but on the exterior it presents evidence of atmospheric oxidation, and is brown in colour; (*a*) is of the interior and (*b*) of the exterior. The analyses are by Mr. E. C. Northcott (Op. ante cit. p. 42). Of two specimens of Rosedale iron ore, assayed by Mr. Smith in my laboratory, the blue-black variety contained 39·38 °/₀, and the bluish dark grey 38·45 °/₀ of iron.

6, *a*, *b*, *c*. Main Seam, ESTON NAB.—The seam is from 12 feet to 17 feet in thickness, and is without any intercalated bed of other material. The analyses are by Mr. Crowder (Op. ante cit. p. 49): *a* is from the top of the seam, *f* from the bottom, and *d* from an intermediate part, nearer the bottom than the top; *a* is described as cinnamon coloured and made up of oölitic grains, *b* as dark blue-green in colour, and *f* as hard, compact, olive-green, and without fossils.

7, *a*, *b*, *c*. Ironstone from HUTTON LOW CROSS.—The analyses are by Mr. Crowder (Op. ante cit. p. 50). The analyses selected are of the ore from three parts of the bed corresponding to those in No. 6: *a* is described as grey, hard, compact, heavy, and with very few oölitic grains; and *b*, *c*, as a softer stone, uneven in fracture, and containing many oölitic grains.

8, *a*, *b*. Upleatham Ironstone.—The analyses are by Mr. Crowder (Op. ante cit. p. 50); *a* is from the floor of the bed, and *b* from an intermediate part; *a* is described as dark-green in colour, compact, and without oölitic grains; and *b* as composed of white grains held together by a green cement, and intersected by green stone without oölitic grains. The proportion of phosphoric acid in *b* appears very small, and a confirmation of this statement is desirable. Another point is extremely remarkable: an analysis is given of the roof of the bed, which is described as cinnamon coloured, friable, and without oölitic grains; and a *trace* only of sesquioxide of iron is put down, whereas it might naturally have been expected that the ore in this part of the bed would have contained most sesquioxide.

9, *a*, *b*. Normanby Ironstone.—The bed at the Normanby mines is about 11 feet in thickness. The analyses are by Mr. John Pattinson, of the Clarence Iron-works: *a* is of an average sample of the upper 3 feet, and *b* of a similar sample of the lower 8 feet (Op. ante cit. p. 51); *a* is described as sage-green, compact, uneven in fracture, and containing a few shells, but very few oölitic grains; and *b* as light bluish-green, filled with oölitic grains.

10. Avicula Bed, GROSMONT, *Yorkshire.*

11, *a*, *b*, *c*. Dogger Bed, GROSMONT, *Yorkshire.**

12. Pecten Bed, GROSMONT, *Yorkshire.*—This and the samples analyzed from No. 10, inclusive, are from the estate of Messrs. Bagnall. Phosphoric acid appears to be present in much smaller proportion in all, except No. 12, than is usual in the Liassic ores of Yorkshire. I am indebted to the Messrs. Bagnall for the following section of the Grosmont mines.

No.		Ft.	In.
1.	Surface—Soil and Clay	12	0
2.	Freestone rock	25	0
3.	Marl and Shale	24	0
4.	Freestone	15	0
5.	Marl	8	2
6.	Coal	0	10
7.	Marl	8	0
8.	Freestone	15	0
9.	Oölitic ironstone (main seam)	15	0
10.	Aluminous shale	185	0
11.	Jet rock	24	0
12.	Sulphur rock	42	0
13.	Topstone (Pecten seam)	0	10
	Shale	1	4
	Thin-band stone	0	6
	Bottom stone	1	8
14.	Shale	3	6
15.	Dogger ironstone	0	10
	Carried forward	382	8

No.		Ft.	In.
	Brought forward	382	8
16.	Shale	4	0
17.	Dogger ironstone	0	8
18.	Sulphur rock, with dogger-stone	12	0
19.	Ironstone, dogger	0	10
20.	Sulphur rock	24	0
21.	Top stone (Avicula seam)	0	10
	Blue shale	0	6
	Three separate beds of stone, called the Thick lift	1	0
	Thin lift, and	0	9
	Bottom lift	0	7
22.	Blue shale	1	6
23.	Dogger ironstone	0	9
24.	Sulphur rock	30	0
25.	Fire clay	4	0
26.	Sulphur rock and marl shales	100	0
	Total	564	1

ASSAYING OF IRON ORES.

Methods of estimating Iron by Dry Assay.

In the dry assay, the button of iron produced always contains carbon, and frequently also silicon, phosphorus, sulphur, and manganese, according to the nature of the ore. The total amount of these matters may range from 3 % to 5 %, or even more. The percentage result is therefore higher than that obtained by wet assay, and should approximate more nearly to that of smelting on the large scale. The assays are made either in brasqued or in unlined crucibles.

1. In brasqued or charcoal-lined crucibles the oxide of iron in the ore is reduced by this lining of charcoal, or by the carbonic oxide, which must necessarily exist in the interior at a high temperature. If the flux is correctly adjusted, the iron will contain the maximum amount of carbon and the slag be practically free from iron.

2. In unlined crucibles, a sufficient amount of carbon must be intermixed with the ore. The slags generally retain a small quantity of iron; the buttons approximate more nearly in weight to that indicated by the wet assay.

Furnace and Implements.

Air Furnace.—One of the furnaces used for assaying in the Metallurgical Laboratory has been previously described.[1] It is well adapted for assaying iron ores. The fuel employed is anthracite, broken up into lumps varying from about 1½ to 3 in. in diameter, and the fine dust being separated by sifting or screening. The furnace should be capable of producing a white heat.

Sefström's blast-furnace.—A description of this furnace has also been previously given.[2] It is commonly used for assaying iron ores in Sweden, where it was first adopted for that purpose. The fuel usually employed in Sweden is charcoal; but hard furnace coke, anthracite, or a mixture of both broken into pieces 1 in. diameter, may also be used. Four small iron assay crucibles may be heated at a time in this furnace. *Deville's blast-furnace*, which has been previously described,[3] is also well adapted for obtaining high temperatures, and the ash and clinker from the fuel are more easily removed from it than from Sefström's furnace.

Crucible and Crucible Mould.—A description of the Swedish iron-assay mould, with the alterations introduced after long practice in the Metallurgical Laboratory, will be found in the First Part of the Metallurgy, and the method of making the small crucibles and lining them with charcoal.[4] For making the crucibles we employ a mixture of about 2 measures of unburnt and 1 measure of burnt fire-clay of good quality; 5 lbs. avoirdupois of unburnt clay and 2 lbs. of burnt

[1] Metallurgy, First Part, p. 454, fig. No. 119.

[2] Op. cit. pp. 231, 232, fig. No. 74.

[3] Op. cit. p. 232, figs. 75 and 76.

[4] P. 228-231, figs. 63, 64, 65, 66, 67, 68, 69.

clay, or, as it is termed, "grog," will make about 6½ dozen crucibles and 2 dozen covers. The waste scraps of clay are used for making the crucible covers. For lining the crucibles a mixture of 4 parts by weight of charcoal powder and 1 part by weight of treacle may be used. A mixture of about 13 oz. avoird. of charcoal powder, and 3½ oz. of treacle, will suffice to line about 48 crucibles. This mixture, with the addition of a little water, should be thoroughly beaten with a pestle and mortar until it is free from lumps, and coheres when pressed between the fingers. After lining, the crucibles should be dried, closed by placing their covers with the flat side downwards, and then heated to redness in a muffle until flame ceases to appear round the mouth of the crucible. They are taken out, and, when quite cold, the covers removed. The lining should be solid, close in texture, free from cracks, and the cavity smooth and well formed. The charcoal plugs required to close the brasqued cavities may be fashioned by means of a coarse-toothed saw, and file, from sticks of ordinary charcoal, or cut out of old linings of crucibles. In Sweden the crucibles are lined with charcoal powder moistened with water, and the lining is afterwards dried. The smallest size (No. 1) French clay crucibles may be used with advantage, if the assayer is not provided with the requisite moulds for making his own crucibles.

Furnace tongs.—Those represented in Fig. 70[5] may be used in adjusting the crucibles in the furnace, and those shown in Fig. 72[5] for removing the support or stand with a batch of crucibles upon it, or large crucibles, when these are employed.

Fluxes.

Silica.—White quartz, or rock crystal, plunged while red hot into water and afterwards pulverized, is preferred on account of its purity; but white sand, such as is used in glass-making, potter's ground flints, or pounded sandstone may be substituted. It is only required in assaying ores deficient in silica.

Glass.—Plate, crown, or window glass, heated to redness and quenched in water and afterwards pulverized, is the material used; it contains from 60 % to 70 % of silica, and, being fusible, it forms a very good substitute for silica or silicates of alumina. A variety of plate-glass used in the Assay Laboratory contains 60·69 % of silica, the remainder consisting of lime, potash, etc. Green bottle glass contains oxide of iron, and flint glass protoxide of lead, and on that account are objectionable.

China-clay.—It is a hydrated silicate of alumina, and forms a very pure and useful flux, as it is practically free from oxide of iron. A sample from Cornwall used in the Assay Laboratory contained of silica, 46·23 %; alumina (by difference), 41·13 %; and water, 12·64 %. The clay is sometimes used in a hydrated, and at other times in a dehydrated state. In the latter case it should be pulverized and then

[5] Metallurgy, First Part, p. 231.

heated to redness; for, otherwise, it would be obtained in hard lumps. 100 parts of the ignited clay contain of silica 53 %, and alumina 47 %.[6]

Shale.—It is silicate of alumina, and is sometimes used on a large scale as a flux in the blast furnace, and is often employed in iron assays. It forms a very good flux in admixture with lime; but it usually contains from 2 % to 5 % of oxide of iron, which is objectionable. It should be free from iron pyrites. The following is an analysis of a shale by Mr. E. Riley:—

Silica	59·23
Alumina	22·01
Peroxide of iron (?)	5·33
Lime and magnesia	2·00
Potash	2·40
Water	9·00
	99·97

Fire-clay.—It is a hydrated silicate of alumina.[7] It is a good flux when mixed with lime, and may be used in place of shale. It may contain from 1 % to 7 % of oxide of iron, and this is objectionable.

Blast furnace cinder.—It consists essentially of silicate of alumina and lime. The white, grey, and nearly colourless glassy varieties should be selected: when reduced to powder it forms a useful flux for ores free from much gangue, or for such as contain silica.

Borax-glass.—It is too fusible for iron assays, as it combines with the oxide of iron at a low temperature before reduction occurs; but is nevertheless sometimes used; when employed as a substitute for glass, shale, etc., the proportions of lime should be increased to diminish the fusibility of the mixture.

Lime.—Common powdered, *unslaked* lime should be used; but limestone, chalk, or any varieties of carbonate of lime form good substitutes. Carbonate of lime contains of lime 56 %, and carbonic acid 44 %: 100 parts of lime are equivalent to 178¼ parts of carbonate of lime. Care should be taken to ascertain that the lime flux is practically free from sulphates.

Fluor Spar or *Fluoride of Calcium.*—White varieties should be selected for use. The presence of quartz is not objectionable. It should, however, be free from metalliferous minerals. It melts at a high temperature, is a very useful flux, and forms fusible compounds with silica and silicates. It may be used either instead of lime or in admixture with it, and it may replace clay as a flux. It contains of calcium 51·28 %, and fluorine 48·72 %: 100 parts of fluor spar are equivalent to 72 parts of lime.

Sampling.

Several pounds weight of lumps should be selected from the heap or bed of iron ore, so as to obtain a fair average sample. This

[6] For analyses of china clay, see Table in Metallurgy, First Part, p. 215, Nos. 28, 29.

[7] For various analyses, see Table in Metallurgy, First Part, pp. 214, 215.

should be reduced in size, well mixed, spread out on a flat surface, and about ¼ in bulk taken out and reduced to coarse powder, and the process repeated until the last portion representing the sample will pass through a sieve of from 40 to 60, and in some cases 80, holes to the linear inch. The ore may be broken down on an iron slab, and powdered in a Wedgwood mortar: iron mortars should be avoided. Some masses of ore, as clay iron ore, are often pretty uniform in structure and composition. With such ores a piece broken off so as to represent a section of the whole, and afterwards reduced to powder, may be regarded as a fair sample. The ore, if necessary, may be dried at about 110° C. Some varieties of earthy brown iron ore contain a considerable quantity of *hygroscopic* as well as *combined* water.

Assay Classification and Proportion of Fluxes.

The flux varies according to the nature of the gangue, and the quantity according to the amount of gangue, size of crucible, and weight of ore taken. The object is so to adjust the flux as to obtain a well-fused, clean slag in sufficient proportion completely to cover the reduced button of metal. Blast-furnace cinder of the following formula may be taken as a type of the kind of slag desirable :—

$$Al^2O^3, SiO^3 + 2(3CaO, SiO^3).$$

Its approximate composition per cent. is as under :—

Silica	38	or about	2½ parts.
Alumina	15		1 ,,
Lime	47		3 ,,

The following mixtures of various fluxes, when fused, produce a slag which may be regarded as approximating to the above composition :—

Quartz	1			1·92	36·5 %
China clay	2 =	Silica	0·92		
		Alumina	0·82	0·82	15·5 ,,
Lime	2½			2·5	48· ,,
Glass	2½	Silica		1·75	35 %
		Materials = to alumina *		0·75	15 ,,
Lime	2½			2·5	50 ,,

* 30 % say of alkalies, lime, etc., on account of its fusibility, are taken as equivalent to so much alumina.

Shale or fire clay	3	Silica	1·8	35 %
		Alumina	0·9	17 ,,
Lime	2½		2·5	48 ,,

If the composition of the ore is known, it is easy to ascertain the amount of fluxes necessary to form a slag with the bases or silica present; and when necessary an extra quantity of the flux should be added, in order to produce a sufficient volume of slag to cover the button.

Example.—Cleveland ore, chiefly carbonate of protoxide of iron :—

	10 grs. of ore contain.		Add proportion wanted.		Add to increase bulk.	Fluxes taken.
Silica	0·86	Sand	1 gr.	+	½ gr.	1½ gr.
Alumina	0·79		0 ,,	+ China clay	1 ,,	1 ,,
Lime, magnesia, and other bases	1·30	Lime	1¼ ,,	+	1¼ ,,	2½ ,,

In practice, analysis is not resorted to to find what amount of silica and bases are present, as it would occupy too much time, and is moreover wholly unnecessary. After due experience little difficulty will be found in properly adjusting the fluxes. In case of doubt, a preliminary trial made on the ore with fluxes in the following proportion will generally suffice to supply the necessary information:—

	Parts by weight.	Parts by weight.	Parts by weight.
Glass	4	2½	1
Lime	1½	2½	4

The three trials may be made at one time. Mixtures of clay and lime may be substituted for the above.

The following *assay classification* of ores and metallurgical products, and the proportions of fluxes which have answered in practice, may be found useful. The proportions given are for 10 grains of ore:—

1. Ores free, or nearly so, from gangue, some varieties of magnetic iron-ore or magnetite, red and brown hæmatite, specular iron-ore, micaceous iron-ore:—

Glass	2½ to 2	Sand	1 to 0
Lime	2½ to 3	China clay	2
		Lime	2½

Blast furnace cinder 5

Fluor Spar 5

2. Ores, etc., containing silica, varieties of brown iron-ore, refinery, tap, and flue cinders:—

Glass	1	China clay	2
Lime	4	Lime	4

3. Ores, etc., containing carbonates of lime, magnesia, protoxide of manganese, etc., calcareous hæmatite, spathic iron-ore:—

Glass	4 to 3	Sand	1
Lime	1½ to 2	China clay	2
		Lime	1½

4. Ores containing silica and alumina, clay iron-ore, etc.:—

Glass	2½ to 0	China clay	0 to 2
Lime	2½ to 3	Lime	2 to 3

If 10 grs. of ore are taken for each assay, the balance should turn with the $\frac{1}{50}$th of a grain. If the assay be made on 100 grains of ore, a balance which turns with from $\frac{1}{4}$th to $\frac{1}{10}$th of a grain will answer. The fluxes should be added in the same relative proportions as before stated, and amounting to about ½ the weight of the ore used.

Practical Directions for Conducting the Process.

Assay in an air-furnace by the Swedish method.—10 grs. of the powdered iron-ore are intimately mixed with glass, lime, or other fluxes. The mixture is made on a piece of glazed paper by means of a spatula, or in a small agate mortar. It is carefully introduced into the charcoal cavity, shaken down, and the cavity is then closed with a plug of charcoal or of old brasque. The top of the crucible is luted over with clay.

Covers may be used, but they are commonly dispensed with. Three or four crucibles are usually put into the furnace at one time, on a piece of fire-brick to serve as a stand. This is adjusted firmly on the bars, the fire lighted, and fuel is put round, but not above, this stand. The crucibles are placed on the stand, the furnace filled with fuel, and the top closed. When the fire has fairly started, which occupies about 10 minutes, the temperature is checked somewhat by slightly opening the top for another 10 minutes, to allow the water and carbonic acid gas to escape slowly from the ore. The furnace is again closed, and the temperature increased to a white heat. In from 30 to 40 minutes afterwards the fire will have burnt down. The top is then opened, and, when the temperature is sufficiently reduced, the crucibles are removed by lifting out the stand on which they rest. They are detached, and, when cold, broken open; and the globule of slag and adherent button of metal removed from the charcoal cavity. The button of iron is cautiously detached from the slag and weighed: any other globules of iron which may be present are separated by crushing the slag in a steel mortar, or wrapping it up in paper and striking it with a hammer. The magnet is used if necessary.

The *slag* is colourless, transparent, and glassy, or white, light-grey, or bluish-grey, opaque and semi-vitreous, porcelain or enamel like.

The *button* is dark-grey and crystalline, or mottled, well formed, and separates clean from the slag.

If the mixture is either pulverulent, fritted, or vesicular, and the iron diffused in minute particles or small globules, the temperature has been too low, or the flux wrongly proportioned. If the slag is dull, opaque, or imperfectly fused, and the button or large globules are smooth on the exterior, somewhat malleable, and difficult to clean from the slag, it generally arises from excess of lime or magnesia, or from an insufficient amount of alumina. If the slag is semi-fused, dark in colour, and the iron in thin laminæ, or the slag resinous, green or greenish-grey, and the button or large globules smooth externally, and non-graphitic, it arises from excess of silica.

The buttons of iron obtained from various assays of the same ore will not vary more than a few tenths of a grain per cent. The following are some results obtained by this method, and calculated for 100 parts of ore.

	1st Batch.				2nd Batch.				3rd Batch.			
Clay Iron Ore	32·2	32·8	32·2	32.3	32·5	32·1	32·4	31·7	32·3	32·2	32·2	–
Calcareous Hæmatite	35·6	35·8	35·5	35·7	35·3	35·6	35·6	35·1	35·5	35·8	35·4	35·5
Spathic Iron Ore	39·8	39·7	39·9	–	39·3	39·2	39·3	39·0	39·3	39·9	39·1	39·8
Hæmatite	71·2	71·9	71·0	71·8	71·3	71·6	71·8	–	71·0	71·8	71·0	71·2

A *batch* of 3 or 4 assays of one variety of ore were in the furnace at the same time, and the results were obtained by different persons.

Peculiarities which have been observed in the presence of various substances are as follows:—

Phosphorus.—The button obtained from tap or flue cinder, and some varieties of bog iron-ore, is generally white, hard, and brittle.

Sulphur.—The button is white or light-grey, or reticulated in structure. It may arise from ore containing pyrites, or sulphate of lime or baryta.

Manganese.—The button is smooth externally, and non-graphitic, hard, breaking under the hammer, and presenting a white, crystalline, or close-grained fracture. The slag is glassy, transparent, amethystine or amber coloured, or glassy, opaque, and yellowish green or brown. These results are often obtained in assaying spathic ores, and some varieties of earthy brown iron-ore.

Titanium.—The button is smooth on the exterior, breaks under the hammer with a dark-grey, dull, or crystalline fracture. It adheres firmly to the slag, which is often resinous, black, and scoriaceous, or curiously wrinkled on the exterior. Externally the slag, and sometimes the button, is coated with a characteristic copper-coloured metallic film of cyanonitride of titanium. Sometimes the slag is vitreous, and has a blue tint.

Chromium.—The product varies from a smooth, well-fused button, with a tin-white, bright crystalline fracture, to a semi-fused white, or light-grey spongy mass, according to the amount of chromium in the iron. Many of the alloys of iron and chromium easily scratch glass. The slag is resinous and dark-coloured, and is sometimes surrounded with a thin metallic layer.

Assay in unlined crucible.—In England this plan is often followed, the quantity of ore operated on varying from 100 to 1000 grains. The assay may be made on the ore before or after calcination. The fluxes employed are chiefly mixtures of shale and lime, or glass and lime, the quantities and proportions varying as before stated. The ore is mixed with charcoal-powder, coke-dust, or anthracite-powder. The amount added is adjusted according to the oxide of iron present, and it should be in slight excess. 100 parts by weight of sesquioxide of iron requires 22½ parts of carbon for reduction. The crucibles used may be black-lead, French, Cornish, or other good clay crucibles. Good black-lead crucibles resist the highest temperature, and may be used more than once. The slag is generally comparatively free from iron, and the iron dark-grey or graphitic. The fine particles of graphite entangle globules of iron on the exterior surface of the slag. French clay crucibles answer well. Cornish crucibles also answer very well, but they soften at the high temperature used for iron assay—a defect which is obviated by allowing the crucible to cool somewhat before removing it from the fire. The crucible-covers are luted down, the crucible introduced into the furnace, the fire made up with coke or anthracite, and the temperature gradually raised to a white heat. The time required to complete an assay is about an hour. The slag should be glassy, transparent, and of a feeble green or grey colour by transmitted light; and the button well melted. Any shots of metal imbedded in the slag may be separated by breaking it up, and afterwards applying the magnet.

The two following assays of Ulverstone hæmatite were made in Cornish crucibles.

I.	Grains.	II.	Grains.
Ore	500	Ore	500
Shale	250	Glass	200
Lime	300	Lime	300
Anthracite powder	120	Anthracite powder	120
Weight of iron obtained	348	Weight of iron obtained	345
Iron	69½ %		69 %

The fracture of the iron was light grey.

Sometimes the dry assaying processes are resorted to with a view to obtain indications concerning the nature and amount of flux which may be necessary in the blast-furnace. This is specially the case in Sweden. The crucibles in this case should be lined with charcoal, plumbago, or other carbonaceous matter, so that the materials of the crucible shall not come in contact with and so influence the fusibility of the ore. The flux used should also be of the same nature as those employed on the large scale.

Methods of estimating Iron by Wet Assay.

The only two processes of any practical use for the estimation of iron, by means of standard solutions, are those by *bichromate of potash* and *permanganate of potash*. For extreme accuracy, rapidity of execution, and directness of application, they leave little to be desired. In both methods the following conditions must be complied with:—

1. The solution of the iron in hydrochloric or dilute sulphuric acids.

2. The reduction of the solution of iron to proto-salt.

3. The conversion of the proto-salt of iron into a persalt by a standard solution.

The reduction of the sesquichloride or sesquisulphate of iron in solution to protochloride or protosulphate of iron may be best effected by metallic zinc or sulphite of soda.

Zinc.—The zinc used should be practically free from iron. Commercial varieties generally contain iron, and sometimes to a considerable amount; and we have frequently found that this is the case with zinc sold in the granulated form. If the zinc be selected in ingot, as sent into the market from the smelting-works, it will generally be found to be comparatively free from iron. That which we have been accustomed to employ contains about 0·10 % of iron. For use it should be melted at a low red heat, and poured from a height of a few feet into hot water, when it is obtained in the form of what copper-smelters term "bean shot." If poured into cold water, it is obtained in the form of "feathered shot," which is too easily broken up by the action of the acid during the assay. Strips of sheet zinc may also be used. If zinc cannot be obtained of sufficient purity, the amount of iron present must be estimated, a known weight of the zinc used in each assay,

and deduction made for the amount of iron contained in it. Zinc may be freed from iron by distillation in an earthen retort. The lead generally present in zinc and left as a black residue by the action of dilute hydrochloric acid does not interfere. The necessary directions to reduce a solution of a persalt of iron by means of zinc will be afterwards stated.

Sulphite of soda.—It may be added in the form of crystals, or a solution may be made and kept ready for use. It gradually absorbs oxygen by exposure to the air, and is no longer fit for use. Reduction of a persalt of iron by means of sulphite of soda is effected as follows:—A weighed amount of ore is to be boiled in acid, and then diluted in a pint flask having a funnel inserted in the neck with about $\frac{1}{2}$ to $\frac{3}{4}$ of a pint of cold water, after which the sulphite of soda is added, and the solution digested at a gentle heat until it is nearly decolourized. The solution is then boiled and kept in ebullition until it becomes colourless, or of a pale green tint, and the odour of sulphurous acid gas cannot be detected. The presence of too much acid should be avoided. If any doubt remains about the complete expulsion of the sulphurous acid, a small piece of zinc may be added, when the odour of sulphuretted hydrogen will be evolved, if any trace of sulphite remains. Sulphite of ammonia may also be used.

The strength of the solutions of the bichromate or permanganate of potash may be found by means of iron wire, sulphate of iron, or sulphate of iron and ammonia.

Iron wire.—*Pianoforte wire* is the best for this purpose, as it is one of the purest forms of manufactured iron. It contains on the average about 99·5 % of metallic iron, the remainder consisting of small quantities of carbon, silicon, etc.; for practical purposes it may be regarded as pure iron. If used for standardizing solutions employed for estimating iron in pig-iron, steel, etc., or where great accuracy is needed, the impurities (0·5 %) must be allowed for. When obtainable, *electrotype iron* is preferable, as it is generally free from foreign bodies, and may be regarded as *pure iron*. Iron wire, which we have been accustomed to use for several years past and tested occasionally by means of solutions of bichromate or permanganate of potash, standardized with electro-deposited iron, contained 99·534 %—99·420 %—99·706 %—99·592 %, and 99·537 % of metallic iron.

Sulphate of iron.—The common crystallized variety is liable to become peroxidized on the surface by keeping. When carefully prepared by the process described, p. 45, it may be kept in a stoppered bottle for years without any sensible alteration, and is a very useful salt for accurate standardizing. It has the formula FeO,SO^3+7HO, and contains 20·14 % of metallic iron. A quantity prepared by this process by Mr. C. Tookey, and the iron estimated by means of bichromate of potash standardized by pure electro-deposited iron, contained 20·14 % and 20·13 % of iron, corresponding to the theoretical amount. Standardized by iron-wire (without any correction) it was equivalent to 20·22 % of iron, and indicates an error of excess of 0·08 %.

Sulphate of iron and ammonia.—It has the formula NH^4O,SO^3+FeO,SO^3

$+6HO$, and when pure has the advantage of containing precisely $\frac{1}{7}$th of its weight of iron, or 14·286 %. We have found it somewhat difficult to expel the last traces of hygroscopic water, even by drying in vacuo, without slight peroxidation. A specimen after desiccation in vacuo during a fortnight became slightly discoloured, had a brownish-yellow tinge, and contained only 14·116 % of iron existing as protoxide, the remainder being peroxidized. It should be prepared according to the method described, p. 45.

Bichromate of Potash Method.

This process was first introduced for the estimation of iron in iron ores by Dr. Penny of Glasgow. It depends upon the fact, that when an acid solution of a protosalt of iron is acted on by a solution containing chromic acid, it is converted into a persalt of iron, with the formation of a sesqui-salt of chromium. The reaction between bichromate of potash and an acid solution of protochloride of iron may be represented by the following formula:—

$$6FeCl+7HCl+KO,2CrO^3=3Fe^2Cl^3+KCl+Cr^2Cl^3+7HO.$$

By ascertaining the amount of bichromate of potash solution necessary to convert a given weight of iron from a proto to a per salt, it is easy by a comparative experiment to estimate the amount of iron in a given weight of ore. The iron solution is first reduced to protosalt by boiling with zinc or sulphite of soda. The completion of the assay is determined by means of a test solution of ferricyanide of potassium.

The reagents required are, for

Test-solution.—This is made by dissolving from 2 to 3 grains of ferricyanide of potassium (red prussiate of potash) in ½ a pint of distilled water. This solution produces a blue or bluish green colour with protosalts of iron, according to the quantity of iron present, but not with persalts of iron, and is used to ascertain the exact point when the solution of protochloride of iron is converted into sesquichloride. For use it should be dotted out by means of a pipette, in small drops of about ⅛ in. diameter, on a white glazed porcelain slab. Large drops should be avoided, as the yellow colour somewhat interferes with the easy recognition of the last tint of bluish *green* on the completion of the assay. If the solution of ferricyanide is made too strong, it gives a reddish precipitate with the solution on testing when the assay is nearly completed.

Standard solution.—305 grains of crystallized bichromate of potash, previously freed from hygroscopic water and pulverized, are to be dissolved in 4 pints (35,000 grs.) of distilled water. 1000 grs. of this solution should be equivalent to about 10 grs. of metallic iron. The crystals quickly dissolve in water, and the solution is ready for immediate use. It should be kept in a well-stoppered bottle, and shaken up previous to use, as evaporation occurs and water condenses on the interior of the vacant part of the bottle; with this precaution the solution when once standardized may be kept for 12 months or more without material alteration. Thus, of 8 pints of solution prepared March, 1858, 1000 grs. = 9·865 grs. of iron; and when reduced in bulk by use

to about half a pint, and restandardized May, 1860, 1000 grs. = 9·888 grs. of iron. The solution of bichromate of potash is standardized as follows:—Two or more pieces of iron wire previously cleaned bright, and freed from every trace of rust by means of sand or emery paper, are accurately weighed. The pieces may vary in weight from 3 to 10 grs., and they should be twisted up into a small coil. Each piece is dissolved in dilute hydrochloric or sulphuric acid in a small conical flask provided with a small funnel or pear-shaped glass bulb inserted in the neck; the acid having been previously heated to expel air, the coil of wire dropped into the hot acid, ebullition kept up, and the flask removed from the source of heat, when the iron is completely dissolved. With these precautions the solution of iron may be easily obtained free from the least trace of yellow colour due to the presence of a sesqui-salt of iron. The solution of iron is diluted with water, transferred to a porcelain basin, the flask repeatedly rinsed out, and water added so as to increase the volume to about 1 pint. The graduated burette is filled up to the uppermost division with the solution of bichromate of potash. The vessel containing the acid solution of iron is placed under the neck of the burette, and the solution of bichromate of potash is allowed to run in slowly until the iron is completely peroxidized, and a drop of the solution ceases to give the *least trace* of bluish *green* colour with the *test solution* of ferricyanide of potassium. The number of divisions on the burette, of solution of bichromate used, is then read off. The remaining pieces of iron are proceeded with in exactly the same manner, and from the data obtained in each experiment, the amount of iron equivalent to 1000 grs. (or 200 divisions) of the solution of bichromate, is calculated, and the mean result taken as the standard. The following results are given in the order obtained. They also serve to show the accuracy of the process:—

Weight of iron wire taken.	No. of divisions of solution of bichromate of potash required.	Calculated amount of iron: 200 divisions (1000 grs.) are equal to
3·795 grs.	76·25	9·954 grs.
5 025 ,,	101·00	9·950 ,,
6·080 ,,	122·25	9·947 ,,
3·158 ,,	63·50	9·946 ,,
	Mean result or standard	9·949 ,,
If 100 grs. of the iron wire contain 99·5°/₀ of pure iron, the standard would be equal to		9·899 ,,

The same solution standardized by means of pure sulphate of iron gave results as follow:—

Weight of sulphate of iron taken.	No. of divisions.	200 divisions = to pure iron.
25 grs. (=iron 5·036 grs.)	101·50	9·923 grs.
20 grs. (=iron 4·0286 grs.)	81·25	9·917 ,,
	Mean result or standard	9·920 ,,

If the sulphate of iron or sulphate of iron and ammonia is used for ascertaining the strength of the solution of bichromate, 15, 20, or

25 grs. of the sulphate of iron, or 25, 30, or 40 grs. of the sulphate of iron and ammonia, accurately weighed, are to be dissolved in 1 pint of water in a porcelain basin, the solution acidified with sulphuric acid, and the process conducted as before described.

The standard of 1000 grs. of solution of bichromate equal to about 10 grs. of iron wire is well adapted for estimating the amount of iron in iron ores or metallurgical products, and is sufficiently near for practical purposes. For exact scientific analysis we employ a solution half the strength of the above, viz., 1000 grs. of solution of bichromate equivalent to about 5 grs. of iron, and calculated to the pure iron standard. The amount of substance operated on should not contain more than about 5 grs. of iron, so that the burette will not require to be refilled during the assay.

Process.—From 10 to 20 grains of iron ore are to be heated with strong hydrochloric acid for about 20 to 30 minutes, in a conical-shaped flask with a small funnel inserted in the neck; when decomposition is completed, the solution is diluted with water, a few pieces of granulated zinc are added, and ebullition kept up until every trace of yellow colour is removed, and the solution becomes either colourless or only of a pale green tint, and free from *fine particles* of zinc. The solution is then transferred to a white porcelain dish, the flask well rinsed out, and the rinsings added to the solution, care being taken that no particle of zinc is carried over at the same time. The solution is diluted to about 1 pint with water, the standard liquor is then run slowly into the solution from a graduated burette, with occasional stirring, until a drop, taken up by means of a glass rod, ceases to give the *slightest trace* of bluish *green* colour when mixed with a drop of the *test solution* of ferricyanide of potassium on the porcelain slab.

As the assay proceeds, the sesquichloride of chromium formed imparts a dark green tint to the solution, and the colour of the bichromate of potash disappears with less and less rapidity as it approaches completion. If the solution assumes a yellow or reddish yellow colour, this arises from a deficiency of hydrochloric acid and consequent non-reduction of the bichromate. After the further addition of acid the assay may be completed, provided excess of the standard solution has not inadvertently been added. When the assay is correctly finished a small quantity of the *test solution* poured into the basin should not produce more than a slight cloudiness. This indication will serve as a check, until experience is gained. When the reduction of the sesquichloride of iron to protochloride is completed, the zinc residue must be allowed to settle down before decantation, or dissolved up by the addition of fresh acid; but this prolongs the assay. No trace of zinc must be present during the addition of the bichromate. Although spathic, blackband, and varieties of clay iron ores form solutions of protochloride of iron by the direct action of hydrochloric acid, the addition of a little zinc is necessary to reduce the small quantity of sesquichloride of iron usually present. When alkaline sulphite has been used, care must be taken to ensure the expulsion of all traces of sulphurous acid.

If a doubt exist as to the complete reduction of the solution of iron to protosalt, a drop may be taken out and tested with solution of sulphocyanide of potassium, when a blood red colour will indicate the presence of a sesqui-salt of iron.

With blackband ironstone, and some varieties of clay iron ore, owing to the presence of organic matter, it is somewhat difficult to know when the decomposition of the ore by the acid is completed. If the ore is finely divided, from 20 to 30 minutes' boiling will ensure the iron being dissolved out. A small quantity of iron in the form of iron-pyrites, or otherwise, is retained in the residue, but it rarely amounts to more than 0·5 % on the ore, and generally less, and for practical purposes it may be disregarded. If it is thought desirable to estimate it, it is better to repeat the assay on the ore calcined previously, when the iron present as pyrites will be oxidized and rendered soluble in the acid. Occasionally some varieties of micaceous hæmatite and magnetic iron ore are met with, which resist the prolonged action of hydrochloric acid, even when very finely powdered. If a weighed quantity of such ore be previously heated for about 10 or 15 minutes in a current of coal-gas or hydrogen in a Rose's reduction crucible, the reduced iron will completely and rapidly dissolve in hydrochloric acid. Fusion with alkaline carbonates or bisulphate of potash may also be resorted to when the ore resists the direct action of acid. The mass after fusion is digested with the acid, and the assay conducted as usual.

The organic matter present in iron-ores does not interfere *chemically* with the action of the bichromate of potash process; but when present in considerable quantity, as in black-band ironstone, it sometimes interferes *mechanically* by remaining suspended, and impairs the tint of colour at the close of the assay. If any difficulty is experienced, the organic matter may be removed by filtration before final dilution. During filtration a piece of zinc should be placed in the filter, the funnel covered with a glass plate, and the washing effected rapidly with hot water. The ore may also be freed from organic matter by previous calcination in a crucible, heated in a muffle or over an air-gas-burner.

Permanganate of Potash Method.

This process was introduced by Marguérite. It depends upon the reaction which occurs between an acid solution of a protosalt of iron and permanganate of potash, a sesquisalt of iron being formed. The reaction, when protosulphate of iron is present, may be represented by the following formula:—

$$10FeO,SO^3+KO,Mn^2O^7+8HO,SO^3=5Fe^2O^3,3SO^3+KO,SO^3+2MnO,SO^3+8HO.$$

A measured quantity of solution of permanganate of potash is required to oxidize a known weight of iron present in solution as a protosalt; the termination of the action is indicated by the tint imparted by the slight excess of the permanganate of potash. For this method *permanganate of potash* is required. When obtainable, crystals are to be preferred. They may be kept for use in a glass stoppered bottle

without alteration, otherwise it may be prepared as follows, the equivalent proportions being 3 of MnO^2, 3 of KO, HO, and 1 of KO ClO5: 8 parts of peroxide of manganese (Swedish), 10 parts of hydrate of potash (fused, pure water-potash), and 7 parts of chlorate of potash, by weight, are to be mixed, and heated to dull redness for about 1 hour. The fused mass is treated with water, and nitric acid cautiously added until the solution changes to a dark purple-violet colour, when it is filtered through a funnel containing asbestos or coarsely-powdered glass, or the residue may be allowed to settle down, and the supernatant liquor drawn off for use. The residue may be used for the preparation of a fresh quantity of the permanganate.

Standard solution.—200 grs. of permanganate of potash crystals are to be dissolved in 4 pints of distilled water. The solution is to be standardized as follows:—A weighed quantity of iron wire is to be dissolved in dilute hydrochloric or sulphuric acid, with the precautions before mentioned. The solution of iron diluted with 2 pints of distilled water in a large flask, with a sheet of white paper under it, or, better still, in a white porcelain dish. When *cold*, the solution of permanganate is to run in slowly, with repeated agitation of the iron solution, until the *faintest tint* of *rose-pink* colour is observed. The number of divisions of solution of permanganate of potash required is noted, and the calculation made. The process is repeated on one or more weighed pieces of iron-wire, and the mean of the nearest results taken as the standard.

The following are some results given in the order obtained. They also serve to show the accuracy of the method. Sulphuric acid was used for dissolving the iron:—

Weight of iron wire taken.	No. of divisions of solution of permanganate of potash required.	Calculated amount of iron: 200 divisions (1000 grs.) are equal to
3·634 grs.	73·75	9·855 grs.
5·350 ,,	108·75	9·837 ,,
7·018 ,,	142·50	9·857 ,,
4·700 ,,	95 25	9·867 ,,
	Mean result or standard	9·854 ,,
If the iron wire contains 99·5 °/₀ of iron, the calculated standard would be equal to		9·805 ,,

The same solution of permanganate, standardized with pure sulphate of iron, gave as follows:—

Weight of sulphate of iron taken.	No. of divisions.	200 divisions = pure iron.
25 grs. (=5·035 grs. of iron)	102·75	9.802 grs.
20 ,,	82·25	9·796 ,,
35 ,,	143·50	9·825 ,,
Mean result		9·802 ,,

An objection raised against solution of permanganate of potash is its liability to decomposition. When prepared from the crystals it may

be kept with slight alteration. The results given above were obtained in March, 1862, and a large quantity of solution was prepared. The residual portion of the solution, standardized in March, 1863, and the results calculated for 1000 grs. of solution, gave as follows :—

By iron wire,	9·811 and	9·783 grs.	
	Mean result or standard	9·797	„
By pure sulphate of iron,	9·766 and	9·747	„
	Mean result	9·757	„
Alteration in 12 months as found by iron wire		=0·057	„
do. do.	sulphate of iron	=0·045	„

For purposes of analysis we employ a solution of 1000 grs., equal to about 5 grs. of iron.

To prepare a standard solution from the strong solution of permanganate of potash, made according to the previous directions, the strength should be approximately found by means of a weighed piece of iron-wire, the solution afterwards diluted to the required strength, and correctly standardized according to the plan already described. This solution is more liable to decompose on keeping, and should be occasionally standardized.

Process.—A weighed amount of the ore is to be acted on by acid according to previous directions, the solution of iron diluted, and reduced by means of zinc or sulphite of soda, and the standard solution of permanganate of potash run slowly into the *cold* solution of iron until a *rose-pink* tint is obtained. The number of divisions are then noted, and the necessary calculations made. Sesquisulphate of iron has a less colouring power than sesquichloride of iron. If hydrochloric acid has been used, by adding sulphuric acid to the water before dilution, the final tint of the permanganate is more easily recognised. It is not advisable to use a burette with indiarubber connector at the lower end. For solution of permanganate the English burette may be used, or Mohr's burette provided with a glass stop-cock, or drawn out into a point at the lower end, and the indiarubber connector and pressure-screw adjusted to the top. If the permanganate is added too quickly, or a sufficient amount of acid is not present, a brown precipitate separates, which generally redissolves by agitation. If the solution is not sufficiently diluted, or the permanganate added before it is cold, chlorine will be given off and the assay spoiled. Iron-ores containing organic matter should be calcined, or the acid solution filtered off according to the directions previously stated, before the addition of the permanganate. During the assay the permanganate disappears with less rapidity as the assay approaches completion. The first change in the tint should be noted, as the pink colour will disappear on standing. After reading off the number of divisions used, a drop of the permanganate may be added; if it increase the tint of the solution, it serves to verify the correctness of the result.

The following are some results obtained, and relating to the preceding descriptions :—

1. A blackband iron-ore, containing 6·96 % of organic matter, gave as follows :—

By a standard solution of bichromate of potash (1000 grs. = 4·87 grs. of iron) on the ore direct without filtering off the organic matter	26·785 % of iron.
Do. on the ore previously calcined	26·785 % ,,
By a standard solution of permanganate of potash (1000 grs. = 4·88 grs. of iron). The organic matter separated by filtration	26·783 % ,,

On attempting to estimate the amount of iron in 10 grs. of the iron-ore, by the same solution of permanganate, in the presence of the organic matter, it took 120 divisions, = 29·28 % of iron, before the pink colour was evident; and even on adding several divisions more of the permanganate, the solution rapidly lost the pink colour.

2. Blackband iron-ore from Bloxwich, containing about 30 % of organic matter :—

Iron estimated by means of permanganate of potash on the ore previously calcined (by R. S.)	= 28·44 %
Iron estimated by means of bichromate of potash after filtering off the organic matter (by R. S.)	= 28·47 %
Do. on the ore direct without filtration (by C. T.)	= 28·38 %
Do. Do. by another solution of bichromate (by H. Coode)	= 28·30 %

The amount of organic matter present in this ore is very large. Two determinations of the iron made with solution of bichromate, in presence of the organic matter, and the solution not sufficiently diluted, gave 26·85 and 26·77 % of iron. The error was found to be due to mechanical interference only; for on filtering off the organic matter further addition of bichromate was found necessary, and the correct per-centage of iron obtained.

We have had both Dr. Penny's and Marguérite's processes in extensive use for several years; but for practical purposes we give the preference to Penny's process by bichromate of potash, for the following reasons :—

1. The bichromate of potash does not require special preparation, as it is a commercial salt, and the crystals easily obtainable.

2. The solution is easily prepared, and is ready for immediate use.

3. After being once standardized, the solution is less liable to decomposition by long keeping than that of the permanganate of potash.

4. It is less liable to error in manipulation, from the evolution of chlorine during the assay, the presence of organic matter, etc.

5. It is equally accurate with the permanganate plan.

6. It occupies less time, as filtration is generally unnecessary, even when organic matter is present in large quantity; and no time is lost in waiting for the assay solution of iron to cool, as is the case with the permanganate.

In the following comparative tabulated results the *wet* assays were made by means of a standard solution of bichromate of potash, or permanganate of potash, and the *dry* assays in brasqued crucibles by the Swedish method.

Comparative Tabulated Results obtained by *wet* and *dry* Methods of Assaying.

ORE. 10 grs.	Wet.	Dry.	Flux in grains.	
Hæmatite	69·75	73·4 73·2	Glass 2 Lime 3	Iron, dark grey graphitic, flattens somewhat before breaking. Slag, white, opaque, crystalline, semi-vitreous.
Do.	68·08	70·4 70·3	Do. Sand ½ China Clay 2 Lime 2½	Do. Iron, dark grey. Slag, vitreous, transparent, and colourless.
Do.	57·57 57·62	59·6 59·9	Glass 2 Lime 3	
Brown iron ore (Northamptonshire)	43·45 43·42	45·0	Glass 2½ Lime 3½	Iron, dark grey. Slag, opaque, vitreous.
Calcareous hæmatite (Froghall)	33·35	35·3 35·6	Glass 4 Lime 1½	Iron, dark grey. Slag, grey white and semi-vitreous.
		35·5	Do.	Iron, mottled. Slag, vitreous and opaque.
Spathic iron ore	[8] 33·95 [9] 34·19	39·8 39·6 39·9	Glass 3 Lime 2	Iron, grey, exterior smooth and hard. Slag, semivitreous, yellowish green.
Do.	34·25	40·4	Do.	Slag, glassy transparent and amber tint.
		39·4 40·0	Sand 1 China Clay 2 Lime 1½	
Clay iron ore	37·55	42·1 42·8	Glass 2½ Lime 2½	Iron, dark grey. Slag, vitreous and greyish white.
Do.	29·37	32·3 32·2	Glass 3 Lime 2	Slag, transparent.
Do.	34·41	37·5	Do.	Iron, dark grey. Slag, vitreous and grey.
Tap cinder	51·05	62·6	Glass 1 Lime 4	Iron, white, brittle, close grained. Slag, vitreous and opaque white.
		63·2	China Clay 2 Lime 4	Slag, do.
Do.	56·54	64·1 64·0	Glass 1 Lime 4	
Do.	57·57	62·1 61·7	Do.	
Titaniferous iron sand	32·13	34·3	Glass 2½ Lime 1½ China Clay 1	Iron, globular, and surface clean and smooth, flattens somewhat, fracture dull, dark grey. Slag, black, hard, resinous, with a copper-coloured film on the external surface.

[8] Reduced by zinc.

[9] Reduced by sulphite of soda.

DIRECT EXTRACTION OF IRON IN THE MALLEABLE STATE FROM THE ORE.

In ancient times iron was always extracted from its ores in the state of *malleable iron*; and to this day the same method is practised by the natives of India, Borneo, and Africa; nor indeed is it yet extinct in Europe: it is stated, moreover, to be still extensively employed in Vermont and New Jersey, U. S.[1] This method will be designated the *direct process*, to distinguish it from the modern or *indirect process*, in which *cast-iron* is first produced. The subject will, accordingly, be treated under these two heads. The apparatus employed is of the simplest kind, consisting of a small furnace or hearth and a blowing machine. Only rich ores are employed, and the fuel is invariably charcoal. A lump of malleable iron is directly obtained, which is hammered out into a solid more or less rectangular mass, called a *bloom*, which is afterwards extended under the hammer into bars. The term bloom is still in common use, and is clearly derived from the Saxon word *bloma*, which is defined by Bosworth as "metal, mass, lump." The ancient furnaces in which the direct process was carried on were designated *bloomeries*.[2] The scale of operation is utterly insignificant compared with the modern indirect process. I shall describe this process as conducted in different parts of the world.

IRON-SMELTING IN INDIA.[3]

The Hindoos appear to have carried on the *direct process* from time immemorial, as we may certainly infer from the large accumulations of slag which occur in various localities in India; and, as it is scarcely possible to imagine anything more rude than their appliances, or anything more diminutive than their scale of operation, it would seem that they have not made any substantial progress in their art, at least in many districts. Their furnaces are frequently not larger than a chimney-pot, and hours of incessant toil are required to produce a few pounds weight of iron; and yet the price at which they sell the metal is surprisingly low. They belong to inferior castes, and their occupation is regarded as degrading. They are, nevertheless, hard-working and useful people, though extremely poor and earning a wretched

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[1] The Manufacture of Iron in all its various branches. By Frederick Overman. Philadelphia, 1854, p. 245.

[2] Contributions to Literature, Historical, Antiquarian, and Metrical. By Mark Antony Lower, M.A., F.S.A. London, 1854, p. 117. The expression *bloma ferri* occurs several times in Domesday Book.

[3] Much has been written on this subject, and I have read everything relating to it that I have met with. I am indebted to Dr. Watson, who has charge of the Museum, etc., belonging to the India Board, for the perusal of numerous tracts, from which I have derived valuable information. Descriptions of native Indian iron-smelting will be found in the following works:—Dalrymple's Oriental Repertory, 1808, 2, p. 488, published by the late East India Company; A Journey from Madras through the Countries of Mysore, Canara, and Malabar, by Francis Buchanan, M.D., 1807, 1, p. 171.

pittance which barely suffices to keep body and soul together. They deserve a better fate.

I am indebted to Mr. Howard Blackwell for a succinct and systematic account of native iron-smelting in India, founded to a considerable extent on his own observation. Mr. Blackwell, under the direction of the Indian Government, explored the mineral resources, especially with reference to coal and iron, of various parts of the country, and, having been himself practically engaged in the management of iron-works in England during several years, was well qualified to observe with accuracy the native processes.[4]

The ores employed are magnetic oxide and rich red and brown hæmatites. Captain Campbell states that he has seen specular iron-ore used by the Konds of Goomsoor.[5] The process of smelting varies somewhat in different districts; and this variation is due partly to local custom, and partly to the fact that the art has most advanced where the population is most dense and civilized.

The furnaces may be divided into three typical kinds. The *first* kind is employed on the western coast of India, in the western Ghâts, and usually through the Deccan and Carnatic, and is the rudest form of furnace in use in the less civilized districts and among the Hill Tribes. The *second* and *third* kinds are employed in Central India and the North-West Provinces, and resemble the simplest forms of the Catalan forge and the German Stückofen respectively: they are greatly in advance of the first, and are capable of producing wrought-iron in considerable quantities, as well as natural steel.

The blast is produced by bellows very unlike those of Europe. The bellows in common use consists of the skin of a kid or goat, taken off the animal by opening the hinder part only; the holes corresponding to the legs are sewn up; at the neck-end is inserted a nozzle of bamboo, and the tail-end is cut transversely, so as to form, when the edges are brought together, a long, straight slit for the admission of air. For a considerable length, but not to the whole extent, of each of the edges or lips composing this slit, a piece of split bamboo is firmly tied on the exterior. By this means the slit may be readily closed or opened, and made to act the part of a valve. The skin should be rendered very supple by rubbing it with oil or buttermilk. Each furnace is provided with at least two such bellows. One man is required to work them, and he sits cross-legged on the ground between them, moving them alternately in order to keep up a continuous and regular blast. A leathern thong passes from one of the lips of the valve round his hand, and to fill the bellows he drops the lower lip and raises the upper one, when air enters, swelling out the skin into the shape of a conical bag. He then quickly catches up the lower lip, closes the

[4] He is the author of the Report of the Examination of the Mineral Districts of the Nerbudda Valley. Printed as No. 144, New Series of Selections from the Records of the Bombay Government. He is now (1862) directing the collieries of that valley.

[5] Calcutta Journ. of Nat. Hist., as quoted in Appendix to the Report of the Government Central Museum of Madras, 1856, p. 12.

valve, and bears with his weight on the inflated skin, forcing out the contained air through the nozzle into the furnace. Large bellows of similar construction are made of buffalo-hide, with the exception that the skin is sewn up along the line of the belly, and the bamboo strips are fixed together at one end of the valve, and can be separated only at the other, where they are prolonged beyond the skin, so as to form convenient handles. Such a bellows requires one man to work it.

Another mode of making and working these bellows is described as follows: "The open end of the skin is finished by folding the edge of one side, as a flap, about 4 inches over the other edge, and sewing up the upper and lower corners, so as to leave a part of both flaps open for about 9 inches. When the skin is filled with wind, and pressed, the inner flap closes therefore against the outer, and stops the passage. Each skin is managed by one man, who places it in his lap, and squeezes it down with the elbow and lower part of the right arm, grasping at the same time a projecting sort of handle of leather, formed at about the part where the tail of the animal might have been. To enable the blower to fill the skin again with wind, a piece of string is attached to the lower corner of the posterior part, which is tied to a peg driven into the ground about a foot behind the man's elbow, and keeps the skin distended to its full extent as it lies in his lap: and a loop of leather is also fastened to the outer flap, through which the arm is passed, by which the opening into the skin is distended upon raising the elbow; and the skin being pulled out horizontally by the neck in one direction, and the string and the peg in the other, upon pulling up the middle part vertically by the leather grasped in the hand, the skin is opened out into a triangular shape, and fills with wind through the open flap. While squeezing the skin in blowing also, by pressing the hand forward so as to pull against the string attached to the posterior part, the valve-flaps are made to close fairly and properly, so as to allow hardly any wind to escape. The left hand is employed in assisting the right, or in squeezing the distended parts of the skin upon the side. It will be observed that, as both the necks of the skins open into the blast-pipe, a portion of the wind expelled from one skin passes back again into the other, as they are worked alternately; a defect which might have been remedied in a most simple manner, by attaching little hanging door-valves to the ends of the pipes."[6]

In Orissa and some other parts of Bengal, bellows of a very different and ingenious construction are in use, and will presently be described.[7] In the Museum belonging to the India Board are small single-acting blowing cylinders of wood, of which the piston is packed with feathers. It will appear in the sequel that such machines are in operation in

[6] On the Manufacture of Bar-Iron in Southern India. By Capt H. Campbell. Appendix to the Report on the Government Central Museum, Madras. Madras, 1856, p. 13. Extracted from the Calcutta Journal of Natural History.

[7] I have specimens of these three kinds of bellows in my collection, for two of which I am indebted to Mr. Blanford, and for a large one of buffalo hide to Colonel Anderson.

Borneo. I shall have occasion to describe an admirably constructed Chinese double-acting blowing machine of wood, in which the piston is also packed with feathers. In the same Museum are preserved most ingenious bellows constructed entirely of leaves.

The tools are much the same at all Indian furnaces. The anvil is of wrought-iron, very small, square, and without the beak of an English anvil, to supply the place of which a separate tool is used. The hammer, tongs, etc., do not differ sufficiently from those in use in Europe to require description.

Hard woods, such as teak and babool (*Acacia Arabica*), are preferred for charcoal; but, failing these, any description of wood is used, and in some places bamboo. According to Mr. Blanford the wood called *sâl* (*Shorea robusta*) is preferred where obtainable. The larger lumps of charcoal are broken to about the size of walnuts, and the dust sifted out.

The ore is brown hæmatite. It is broken into small particles not larger than peas, and the fine dust produced in the operation of crushing is carefully sifted out and thrown aside.

First kind of furnace.—It varies in size, and sometimes in shape; but the principle of its construction and the method of working are always the same. In its simplest form, among the Hill Tribes of the Ghâts, it is only 2 ft. high, and yields 5 or 6 lbs. of iron at a charge, while, in its more advanced state in the Deccan, it is often 4 ft. high, and produces 30 lbs. of iron at a charge. It is circular in form; its width at the bottom or across the hearth is from 10 in. to 15 in., and at the top from 6 in. to 12 in.; and, as stated above, its height ranges from 2 ft. to 4 ft. It is built entirely of clay carefully tempered. In use the lower part wears rapidly away, and is constantly repaired with a lining of fresh clay. There are two openings into the bottom of the furnace, through one of which the blast is admitted, and through the other the slag or *cinder* and the iron produced are removed. With respect to this practice Mr. Blanford informs me, that in all the furnaces which he has seen in Bengal and the Carnatic the cinder runs out at the side, and the iron is withdrawn through the same aperture as that through which the twyers pass.

The operation of smelting is conducted in the following manner:—The furnace, if a new one, is carefully dried by keeping a fire in it for some hours. Two earthen pipes or twyers about 12 in. long and 1 in. in internal diameter are placed side by side in the opening at the front of the furnace, so as to project 2 in. or 3 in. into the interior of the furnace, and be 3 in. or 4 in. above the bottom, and with each of these twyers a bellows is connected. The remainder of the opening is then filled with clay, and the front opening is in like manner stopped. The furnace is now filled nearly half full of charcoal, and upon this fire is put, after which it is filled up to the top with charcoal. The blast is then applied. The smelters attach a good deal of importance to the kindling of the fire at a proper height above the twyer, and as it extends downwards very slowly a small quantity of charcoal remains unburnt in the bottom of the furnace until almost the end of the operation.

When the charcoal sinks at the top of the furnace, alternate charges of ore and charcoal are supplied until the proper charge of ore has been introduced, after which the blast is increased as much as possible and thus maintained till the close of the operation. Cinder soon appears in the hearth, and, when it rises to the twyers, is tapped off by inserting a small bar through the fore part of the furnace. The greater part, however, of the cinder remains in the furnace and is taken out along with the iron. In from 4 to 6 hours a charge is completed, when, the front of the furnace being removed, a small mass of malleable iron, cinder, and unburnt charcoal is drawn out. If the operation has been properly conducted, the iron is sufficiently hot to be hammered at once into a tolerably sound *bloom*, with the extrusion of a thick viscid cinder; but it is sometimes too cold for this purpose, and must in that case be reheated in an open charcoal fire.

As a large part of the front of this furnace is removed at the end of each successive charge in order to extract the iron, much time is wasted and fuel lost from the cooling of the furnace. Hence, it is generally impossible to work off from one furnace more than two or three charges daily.

In districts where this kind of furnace is in operation, there is usually no division of labour, the same family collecting the ore, burning the charcoal, making the iron, and immediately afterwards working it up into such articles as may be required by the villagers. The smelters are sometimes itinerant, going from village to village and setting up their furnace wherever a demand for iron exists, and a supply of ore and charcoal can be obtained.

Second kind of furnace.—It is generally employed through Central India and the North-Western Provinces, in which manufactures of all sorts have acquired a much greater development than in the districts before mentioned.

The iron-makers here are united in villages of which the sites have been determined by the proximity of ore and wood of good quality for charcoal. In the larger villages there is usually a complete subdivision of labour, miners, charcoal-burners, smelters, and blacksmiths forming separate classes; and the iron is frequently sent for sale to considerable distances from the places of manufacture.

The descriptions of the *second* as well as *third* kinds of furnaces are taken from examples occurring in Tendukera, probably the largest iron-making town in India, and containing from 50 to 60 of such furnaces.

The *second* kind of furnace consists of a bank of well-tempered clay in which is a cylindrical cavity from 15 in. to 18 in. in diameter, and about 2 ft. 6 in. deep. The bank is frequently extended in length, and contains a row of two or three similar cavities at convenient distances from each other. At the bottom of each cavity are two openings on opposite sides.

The mode in which the ore and charcoal are prepared and the furnace set to work is much the same as in that just described. The furnace being filled with charcoal in the first instance and the blast

applied, ore and fuel are charged alternately. When the cinder has accumulated to a certain extent in the hearth, it is tapped off through the front by inserting an iron bar; but when a charge of iron is ready, it is taken out through the top of the furnace by means of a pair of tongs, having previously been formed into a ball, with an iron bar also introduced through the top. As soon as the ball is removed, the cinder remaining in the furnace is tapped off through the front, and fresh charges of ore and charcoal are supplied. Hence, the principal defect of the *first* furnace does not exist in this; for as the iron is to a certain extent manipulated in the furnace itself and then removed without the destruction of the lower part of the furnace, it is possible to charge again without delay or allowing the whole structure to cool. Six lumps of iron of about 20 lbs. in weight each are made in the day of 16 hours, and hammered without reheating into sound blooms. This furnace is obviously a considerable improvement on the first, and is in fact a small Catalan furnace.

Third kind of furnace.—It is employed in the same district as the *second*, but for the manufacture of a superior quality of iron and of natural steel. It is built of clay, and is usually placed in the side of a mound. Its entire height on the outside is from 8 ft. to 10 ft., and within from 6 ft. to 7 ft., so that the bottom of the hearth is from 2 ft. to 3 ft. above the ground. It is 18 in. square in the interior, and of the same size from top to bottom. Its front wall is usually not more than 5 in. or 6 in. thick, so as to admit of its being removed at pleasure; and when this is done the body of the furnace presents the appearance of a vertical trench 18 in. square, cut in the front of a mound of well-tempered clay. The working bottom of the furnace is formed by a plate or tile of dried clay, in which are a number of small holes punched nearly through, and which is placed at an angle of about 45° with the back of the furnace.

A modification of this furnace is sometimes used, in which the cross-section is about 15 in. by 21 in., instead of 18 in. square; and the fuel consists of alternate charges of charcoal and wood. This furnace works well, but possesses no peculiar advantage.

In setting the furnace to work, the bottom plate or tile is first put in, and then cow-dung is introduced to the depth of about 12 in. On the top of this bed of cow-dung about 4 in. or 5 in. above the front edge of the bottom plate are placed two earthen pipes or twyers, which are at least 18 in. long, and project into the furnace almost to the back. The furnace is then partially filled with charcoal, lighted, and afterwards filled to the top with charcoal. The blast being applied from the front, the man who works the bellows sits upon a sort of scaffold raised 2 ft. or 3 ft. from the ground. Ore and charcoal are alternately charged, and the smelting continues from 12 to 16 hours. A considerable quantity of cinder is tapped out at intervals by passing an iron bar through the semi-perforations in the bottom plate into the furnace, beginning first with the lower holes and afterwards proceeding to the upper ones; the holes from which the cinder has been drawn are stopped with clay in turn, as the iron accumulates at the bottom

and extends up to them. When the twyers are entirely burnt away, the iron having risen to their level, the smelting is completed; the bottom plate is then removed with an iron bar, and the mass of iron and cinder which has collected in the bottom of the furnace allowed to fall to the ground. The lump of iron frequently weighs from 150 to 200 lbs., and is too large to be hammered whole. It is, therefore, cut by means of a sharp-edged sledge, so that when cold it may be broken into four pieces. It usually consists of a mixture of malleable iron and natural steel, the relative amounts of which are stated to depend more upon the nature of the ore than any modification of the process. When, however, the object is to produce steel, a large proportion of charcoal is employed and a gentle blast applied. The steely parts frequently present the same appearances on fracture as the best blister steel from Swedish iron; and they are carefully selected and prepared for use by being heated to a low red-heat in a charcoal fire and then cut into small pieces of convenient size for making edge-tools, etc. When iron is wanted instead of steel, the pieces into which the lump has been broken are raised to a welding heat and hammered into bars, by which means it loses almost all appearance of steel. Sometimes small quantities of cast-iron are produced in this furnace to the great annoyance of the smelters, who have much difficulty in separating it from the rest of the iron. They consider that in this case the iron has been injured by raising the temperature of the furnace too high.

The last or *third* kind of furnace differs so much in certain details from a furnace evidently belonging to this class described by Aikin[*] from a MS. of Major Franklin, that I insert a short account of the latter. The accompanying diagrams of this furnace will render any lengthened description unnecessary.

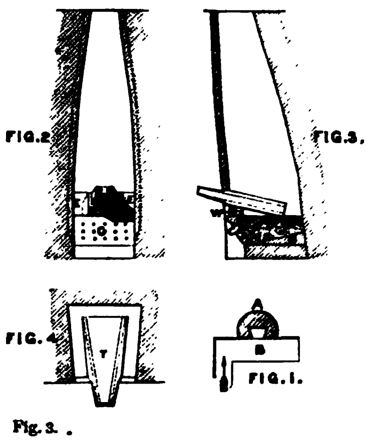

Fig. 1, ground plan. A, the furnace: the walls are made of large unburnt bricks and lined with clay. B, a trench 3 ft. deep, having a sloping entrance, as shown by the arrow.—Fig. 2, front elevation.—Fig. 3, vertical section.—Fig. 4, the twyer, T, composed of two diverging earthen pipes imbedded in a mass of dried clay. H, hearth-bottom of sandstone, or some other hard and difficultly fusible rock: its surface slopes towards the front. C, plate of clay, perforated with holes, which are opened or stopped up according to circumstances. W, a clay wedge for regulating the dip of the twyer. E E, plates of burnt clay or thick tiles that fill up the space in front of the furnace not occupied by the twyer. D, a mass of cow-dung and chaff. There are two bellows to a furnace, which are fixed in front at a convenient height from the ground. The twyer is kept firmly in its place by a vertical bar, the bottom of which presses on it, while the top is hitched into a loop of iron placed between two lateral studs or staples.

[*] Illustrations of Arts and Manufactures. By Arthur Aikin. London, 1841, p. 289.

The entire height of the furnace varies from 4 ft. 4 in. to 8 ft., and its diameter at the widest part from 1 ft. to 3 ft. 9 in.

It will be observed that the back of the furnace inclines considerably forwards, and this is stated to be an essential condition of its construction.

By way of special illustration of the *first* kind of furnace I have pleasure in presenting a description of iron-smelting in Orissa, Lower Bengal, from the pen of my friend and former student, Mr. H. F. Blanford, recently of the Geological Survey of India.

"The form of furnace shown in the accompanying woodcuts is that used in the Tributary Mehals of Orissa, but with some slight modifications may be regarded as typical of those employed generally by the natives of Lower Bengal. The furnace from which the original sketches of the woodcuts were taken was seen by me in operation in the village of Kunkerai,[9] which, like all such villages in this part of Bengal, is inhabited exclusively by the iron smelters, and is distinguished from the agricultural villages around by the filth, poverty, and degraded condition of the inhabitants. The iron smelters of Orissa, as I believe, generally in Bengal form a class apart from the agricultural inhabitants, belonging, indeed, to the isolated aboriginal tribes which, under varying names, are found in all the hilly tracts of the peninsula, and are regarded by modern ethnologists as the degenerate relics of the aboriginal Tamul race. In Orissa there are several of such tribes, differing in their relative degrees of civilisation: the iron smelters of the Talcheer and neighbouring districts belong to the large tribe of the Kōls or Coles. They are to a certain extent nomadic in their habits, remaining in one spot only so long as plentiful supplies of ore and wood are obtainable in the immediate vicinity. These failing, or, as frequently happens, on the occurrence of anything that is regarded as of evil omen by these superstitious communities, they transport themselves and property to some more propitious site, and work away as before. The heavy rains and increasing jungles soon obliterate the remnants of the deserted village, with the exception of the large accumulations of slags, which remain for centuries, monuments of an unprogressed art. Such lumps of slag are frequently found in jungly districts, where no iron manufacture has been carried on within the memory of the inhabitants.

"In the furnace here shown the only essential parts, *i. e.* parts common to all the furnaces of Orissa, are the cylindrical portion or furnace proper and the bellows apparatus. The inclined earthen tray with its wooden and bamboo supports I have only seen in a few villages. The furnace is of the rudest construction. It is built of the highly ferruginous sandy soil of the country, moistened and kneaded, and is generally strengthened by a sort of skeleton of strips of flexible wood. See sections, figs. 6 and 8, over which the earth is worked. In form it varies from a cylinder, more or less circular, to a frustum of a tolerably acute cone, the walls being either of equal thickness (about 3 inches) throughout, or rather thicker towards the base. The height of the furnace is generally about 3 feet, and the mean internal diameter about 1 foot; but all the dimensions vary according to the skill of the workman, or, more probably, according to local custom or chance. There are two apertures at the base of the furnace: one in front, about a foot in height, and rather less in width than the internal diameter of the furnace, through which, when the smelting of one charge is finished, the resulting mass of spongy iron is extracted, and which, *during* the smelting, is well plastered up, the small conical twyer being inserted at the bottom. This twyer is usually made of the same material as the furnace, viz of a red argillaceous sand, worked by hand into the required form and sundried; but sometimes no other twyer is employed than a lump of moist clay with a hole in it, into which the bamboo pipes communicating with the bellows are inserted.[1] The other aperture is smaller, and

[9] See Mem. Geol. Survey India, Part I. pp. 60, 65, &c.

[1] "See p. 16 of Report on Coal and Iron of Cuttack. Most of this Report is taken from a MS. of my brother's, except such parts as are taken from published works."

placed at one side of the furnace and chiefly below the ground, forming a communication between the bottom of the furnace chamber and a small trench into which the slag flows, filtering out through a small pile of charcoal (see *b*, figs. 4, 5). The bed of the furnace is slightly inclined towards this slag-hole to allow the slag to flow away freely. The latter solidifies as it leaves the furnace into vesicular cakes, which are removed occasionally with pincers by the workmen.

"The inclined tray at the back of the furnace is, as above stated, very locally employed. It is formed of the same material as the furnace, kneaded into shape, and supported on a bed of split bamboos laid on a wooden framework. On it is piled a supply of charcoal which is raked into the furnace as required.

"The blowing apparatus employed in Orissa is very ingenious, and is perhaps as economical of human labour as any form of hand-bellows. Sections of it are shown in figs. 9, 10, in the one case extended, in the other compressed. It consists of a circular segment of hard wood, usually mango-wood, rudely hollowed, and with a piece of buffalo hide with a small hole in its centre tied over the top. Into this hole a strong cord is passed, having a small piece of wood attached to the end to keep it inside the bellows, while the other end is attached to a bent bamboo firmly fixed into the ground close by. This bamboo acts as a spring, drawing up the string and consequently the leather cover of the bellows to its utmost stretch, while air enters through the central hole. When thus filled, a man places his foot on the hide, closing the central hole with his heel, and then throwing the whole weight of his body on to that foot he depresses the hide and drives the air out through a bamboo tube inserted in the side and communicating with the furnace. At the same time he pulls down the bamboo with the arm of that side. Two such bellows are placed side by side, thin bamboo tubes priming to the same twyer; and so, by jumping on each bellows alternately, the workman keeps up a nearly continuous blast.

"I have never seen this form of bellows elsewhere than in Orissa. The bellows employed vary greatly in different parts of India.[2]

"The drawings are much idealized as regards regularity and neatness of construction, but the dimensions, etc., are accurately copied from the original. The native is far too intellectual, muscular, and clean for any Kōl that ever lived."

The slags contain rounded particles of iron, which are separated by pounding and washing, and are used instead of leaden shot.

Dr. Hooker has published a brief notice of native iron-smelting in the Nonkreem valley, in the Khasia mountains. The ore is described as iron-sand (magnetic oxide?) disseminated through coarse reddish sand resulting from the decomposition of soft granite occurring in the locality. In order to procure this iron-sand, the natives conduct water over the beds of granite sand; and as the lighter particles are washed away, the remainder is removed to troughs, where the separation of the ore is completed. The ore must be very abundant, as Dr. Hooker states that "the country is everywhere intersected with trenches for iron-washing, and some large marshes were dammed up for the same purpose." "The smelting," Dr. Hooker states, "is very rudely carried on in charcoal fires, blown by enormous double-action bellows, worked by two persons, who stand on the machine, raising the flaps with their hands, and expanding them with their feet." In

[2] This kind of blowing apparatus was described and figured by Mr. Robert Rose in the Gleanings of Science, No. 34, Oct. 1831. Calcutta. It was observed by him in use for making iron at Amdeah, near Sambhalpúr.

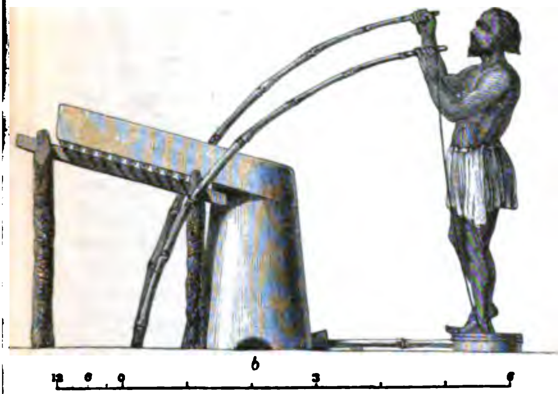

Fig. 4. Side elevation.

Fig. 7. Front elevation.

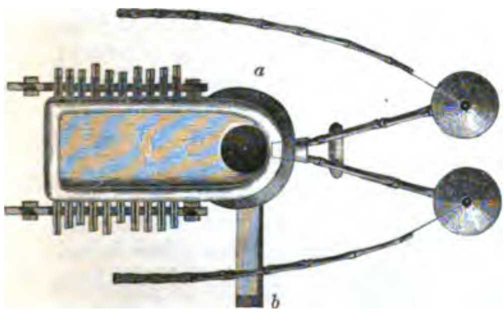

Fig. 5. Plan.

Fig. 8. Vertical section on the line *a b*, fig. 5.

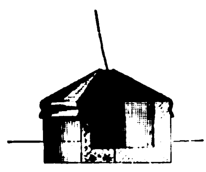

Fig. 9. Vertical section of one of the bellows.

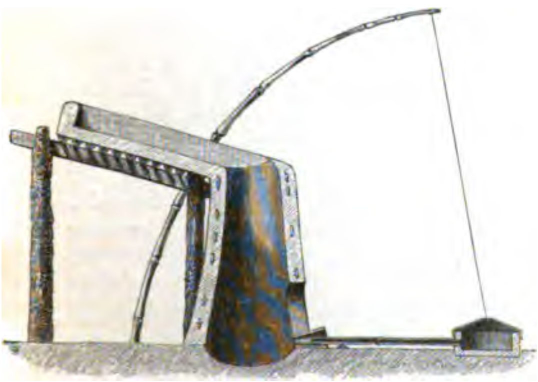

Fig. 6. Vertical section through the centre and one of the bellows.

Fig. 10. Section of one of the bellows, showing the action of the heel in depressing the skin and closing the opening in its centre.

illustration of this Dr. Hooker has given the annexed woodcut, which is from the same block as that in his work. "There is neither furnace nor flux used in the reduction. The fire is kindled on one side of an upright stone (like the head-stone of a grave), with a small arched hole close to the ground: near this hole the bellows are suspended; and a bamboo tube from each of its compartments meets in a larger one, by which the draught is directed under the hole in the stone to the fire. The ore is run into lumps as large as two fists, with a rugged surface: these lumps are afterwards cleft nearly in two, to show their purity."[3]

Fig. 10 a. Iron Furnace, Khasia Mountains.

If Dr. Hooker's engraving had not been accompanied with a specific description, I should have supposed that it was intended to represent a charcoal fire used solely for the purpose of re-heating the iron during the operation of hammering it out into bars or other forms. Details of the construction of the bellows would have been desirable. As shown in the engraving, they seem capable of being worked by the feet alone; for, by means of the attachment between them, as the air would be expelled by pressing obliquely with the foot on one side, the other would by the same action become inflated. The two sides may be thus alternately filled and emptied, so as to produce a continuous blast. The attractive damsel figured by Dr. Hooker will naturally excite the sympathy of the reader. I have met with another description of iron-smelting in this district, illustrated by a very artistic

[3] Himalayan Journals. London, 1854, 2, p. 310.

etching, which leads me to infer that the bellows seen by Dr. Hooker were worked as I have suggested. The furnace in this account is obviously a *smelting* furnace, and widely differs from that described by Dr. Hooker. I insert the following extract, which, though short, is pretty clear and explicit.[4]

"There are large grass huts at least 25 ft. high, the thatch of which reaches down to the ground on all sides. The interior, of an oval form, 15 by 20 ft. in the two diameters, is divided into three apartments; the central one being the smelting-room. Two large double bellows, with the nozzles pointed downwards, are set up on one side of the apartment, on the upper part of which a man stands with one foot on each, his back supported by two planks. He holds a stick in his left hand, which is suspended from the roof, and has two strings attached to it below, connected with the two bellows: these are worked quickly by a wriggling motion of the loins, and the strength of the leg. The nozzles of the bellows unite in a tube which leads underground, from a sort of wind-chest, to the hearth about 4 ft. in front of them. Over the hearth is a chimney of pipe-clay braced with iron hoops, 2 ft. in diameter at the bottom, and about 6 ft. high. The mouth at bottom is on the side away from the bellows. and the chimney inclined from them to direct the heated air from the smelter towards an opening in the roof. At the right side of the bellows, and even with the top of the chimney, is a trough containing damp charcoal and iron-sand: at every motion of his body the operator with a long spoon tumbles a piece of this charcoal, with the iron-sand adhering to it, down the funnel of the furnace, and when a mass of melted, or rather softened, iron is formed on the hearth, it is taken out with tongs, and beaten with a heavy wooden mallet on a large stone by way of anvil. The iron in this state is sent down to the plains for sale or barter." The fire-clay employed is said to be procured in large quantity near a limestone hill in the vicinity.

The bellows represented in the illustrative etching seem to be composed of wood and skin or leather, and closely to resemble ordinary European bellows.

One would naturally suppose that voracious iron-works, consuming as they do almost every living plant or tree in their vicinity, and changing a beautiful landscape into a hideous desert, would be regarded with peculiar abhorrence by an ardent and illustrious botanist, like my friend Dr. Hooker. But, so far from this, the metallurgist will be gratified to learn that Dr. Hooker, with a catholicity of scientific feeling which is somewhat surprising, indited the following passage even in view of the gorgeous scenery of the Himalayas:—"Few houses were visible, but the curling smoke from the valleys betrayed their lurking-places, whilst the tinkling sound of the hammers from the distant forges on all sides was singularly musical and pleasing; they

[4] Smelting of Iron in the Kasya (*sic*) Hills. Jour. of the Asiatic Soc. of Bengal, 1832, 1, p. 150. The etching is by Mr. J. Prinsep, and the drawing from which it was made and the notice are by Mr. W Cracroft.

fell on the ear like 'bells upon the wind,' each ring being exquisitely melodious, and chiming harmoniously with the others. The solitude and beauty of the scenery, and the emotions excited by the music of chimes, tended to tranquillize our minds, wearied by the fatigues of travel and the excitement of pursuits that required unremitting attention; and we rested for some time, our imaginations wandering to far-distant scenes, brought vividly to our minds by these familiar sounds."[5] Whether the "sweet music" of the forges, or the associations which they excited in the mind, contributed most to the inspiration of Dr. Hooker when he wrote this glowing passage, must be left to the decision of the reader.

Commercial Details.

A few authentic statements concerning yields and cost of extracting and manufacturing iron in India by the native methods may interest and perhaps rather astonish British as well as Continental iron-masters.

In Southern India (1844) lumps, as they come from the furnaces, and weighing about 11 lbs., are sometimes sold at the rate of 2 annas (3*d.*) each. But the best lumps in forging yield only about 6 lbs. of iron, and generally not more than 3 lbs. The expense of forging the crude lumps of iron into rough bars by hand-hammers may be estimated at 40 rupees (4*l.*) per ton of the former; so that the expense of the bar-iron will be 80 rupees (8*l.*) per ton, which a few years ago, when the above statement appeared, was less than the market price at Madras of the cheapest English bar-iron.[6] To work a furnace about 4 ft. high, four men are required, one master and three labourers, and they only make 3 lumps in the day of 12 hours. Captain Campbell states that in small blast-furnaces not larger than the native ones, he was able with two men to produce 40 lbs. of crude iron in a day of 12 hours, with an expenditure of half the quantity of ore and charcoal consumed by the natives.[7] The same writer asserts that the worst Indian iron he has ever seen is as good as the best English iron, and he supposes that the alleged defects of the former were due to its almost always containing a considerable portion of steel. Iron produced in his own native furnaces in Southern India could be drawn out under the hammer into a fine nail-rod not $\frac{1}{16}$ inch thick, without splitting, and might be bent backwards and forwards 6 or 7 times before it broke. It could be twisted to a considerable extent without fracture, and a half-inch bar $\frac{1}{4}$ inch thick bore doubling together *cold* and hammering down close to the angle with very little appearance of separation between the fibres. Indian iron of native manufacture is stated by some to be generally red-short, cracking at the edges when

[5] Op. cit. 2. p. 295.

[6] Captain Campbell, on whose authority these statements are made, subsequently corrected this estimate to 90 rupees (9*l.*) per ton of bar-iron, on the ground that he had not made a proper allowance for the waste in forging.

[7] Appendix to the Report on the Government Central Museum of Madras, p. 14.

worked hot under the hammer; but, according to Captain Campbell, such iron is not common.[8]

At Arnee, Madras Presidency. Washed iron-sand is the ore used. 100 lbs. yield 33¼ of crude iron. Weight of iron at one smelting 10 lbs. 12 ozs. 10½ dwts. By forging, 100 lbs. of crude iron yield 33¾ of bar-iron, of which, therefore, the ore gives 17°/₀.[9]

North Canara, the most northern of the Madras Collectorates. Average price of crude iron of native manufacture 2 rupees a maund (80 lbs.), *i. e.* 5*l.* 12*s.* per ton. About 2½ maunds (200 lbs.) are obtained from each furnace at one smelting.

Malabar, Madras Presidency. The quantity of iron produced yearly in this district may be estimated at about 475 tons (of 2240 lbs.) The selling price of (crude?) iron averages from 12 annas to 1½ rupee per toolam (28 lbs.)—is, say 6*l.* per ton. The average price of charcoal, which is brought from 1 to 8 miles, is at the furnaces 1½ anna per 65 lbs., the amount one man can make in a day. To produce 1 lb. of crude iron 6 lbs. of charcoal and 4 lbs. of ore are required. The crude iron in forging loses nearly half its weight. The estimated profit to the smelter was 10 rupees or 1*l.* per ton.[1]

Name of locality.	Cost of furnace with shed.		Cost of working per month, according to size of furnace.	
Talook.	Rupees.		Rupees.	
Koormenaad......	5	10*s.*	10 to 30	1*l.* to 1*l.* 10*s.*
Shernaad	6	12*s.*	20	2*l.*
Walloowanaad...	17 to 30	1*l.* 14*s.* to 3*l.*	17 to 52	1*l.* 14*s.* to 5*l.* 4*s.*
Ernaad	12 to 15	1*l.* 4*s.* to 1*l.* 10*s.*	52	5*l.* 4*s.*
Temalapooram...	24 to 48	2*l.* 8*s.* to 4*l.* 16*s.*	2½[2] to 28	5*s.* to 2*l.* 16*s.*

Salem, Madras Presidency. The cost of a furnace varies from 4 annas (6*d.*) to 2 rupees (4*s.*), the quantity of ore they are capable of containing being from 15 to 18 lbs. This is stated to be the principal seat of the steel manufacture.[3]

Vizagapatam, a maritime district, Madras Presidency. 100 lbs. of ore yield 25 of crude iron. 1¾ lb. of crude iron produces 1 lb. of bar-iron.

Coimbatore, Caroor talook, Southern India, Madras Presidency. In

[8] Captain Campbell, who was Assistant Surveyor-General, Madras Establishment, has evidently something to learn concerning the nature of British iron ores, as will appear from the following extract from one of his papers:—"I have little doubt that excellent iron might be made from the English iron-stones, *if the oxide of iron was separated from the impurities by washing.*" The italics are mine. Appendix to Report, etc., ante cit. p. 26.

[9] Captain Brooke. Report on the Government Central Museum, Madras, by Edward Balfour, Surgeon, Madras Army. On the Iron Ores, the Manufacture of Iron and Steel, and the Coals of the Madras Presidency. Madras, 1855, p. 24. The other details which succeed are derived from the same volume, when not otherwise stated.

[1] Rep. ante cit. H. Conolly, Collector. Calicut, June 24, 1854.

[2] This seems very small. It is, however, so stated.

[3] J. M. Heath. Appendix to Report on the Iron Ores, etc., ante cit. p. 2. Quoted from Journal of Asiatic Society, 5, pp. 390-7.

this locality I find the smallest amount set down as the cost of erecting a furnace, about 4 ft. high and 1 ft. in diameter; it is only 1 anna 6 pice (2¼*d.*)! One man working hard for 3 days can make 4 furnaces. The cost of working is the price of labour for 4 people to 1 furnace for a month, which may be from 7 to 8 rupees (14*s.* to 16*s.*).[4]

Nagpore, Southern India, Deccan. The furnaces cannot be worked in the rains, as they are all under trees in the open air. The entire cost of a furnace is estimated not to exceed 1 rupee! There are three men to each furnace. The daily expense may be for ore ½ anna (¾*d.*), charcoal 2 annas (3*d.*), labour 3 annas (4½*d.*)—total 5½ annas (8¼*d.*) From each furnace is produced 1¾ maund of crude iron, which by forging yields 1 maund of bar-iron.

Throughout Kumaon and Gurhwal, Northern Hindostan, Bengal Presidency, the average price of charcoal delivered within 4 miles of the forest is about 3 annas (4½*d.*) for 30 seers (60 lbs.), or about 14*s.* 8*d.* per ton (of 21 cwt.).[5]

Kumaon district. 930 seers of ore produce 327¾ of crude iron or bloom-metal, which in its turn produces 81¾ seers of marketable bar-iron; *i. e.* 100 parts by weight of ore yield only 8⅕ of bar-iron.

930 seers of ore require 340 seers of charcoal to produce 327¾ seers of bloom-metal, which, in its turn, requires 327 seers of charcoal to produce 81¾ seers of iron, *i. e.* for 1 part by weight of iron 8⅙ of charcoal are required.[6]

The most recent information which I have met with concerning the price of iron of native manufacture is contained in a report by Mr. Howard Blackwell,[7] to whom I have already had occasion to acknowledge my obligation. This report is evidently truthful and business-like, and may, I am convinced, be received with confidence.

According to Mr. H. Blackwell, the town of Tendukera in the valley of the Nerbudda is, as has been previously stated, entirely engaged in iron making. The ore is a calcareous hæmatite occurring in limestone, about 2 miles south of the town and 4 miles from the north bank of the Nerbudda river. The workings extend over a space of 400 or 500 yards in length and about 200 in width. The ore is obtained at a depth of from 30 to 40 ft. below the surface; but it also occurs in larger or smaller quantities up to the surface. The pits are sunk every season, being all washed in by the rains; and the whole system of working is as rude and wasteful as it can possibly be. The charcoal used is obtained from hills to the north from 4 to 10 miles from the town. Every sort of wood, hard and soft, is used indiscriminately; and the jungle producing it is cut every 4 years.

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[4] E. C. G. Thomas, Assistant Collector. Appendix to the Report, etc., ante cit.

[5] Report on the Metalliferous Deposits of Kumaon and Gurhwal in North-Western India. By William Jory Henwood. Calcutta, 1855, p. 33.

[6] Selections from the Records of Government, North-Western Provinces. Published by authority. Agra, 1853, Part 13. Iron and Copper Mines in the Kumaon Division, by J. O'B. Beckett. Report dated Jan. 31, 1850, pp. 67 et seq.

[7] Report of the Examination of the Mineral Districts of the Nerbudda Valley. By J. H. Blackwell, Esq., Mineral Viewer for Bombay. Bombay, printed for the Government. 1857.

The charcoal is brought to the town in baskets upon the backs of buffaloes, and sold at from 3½ to 3 buffalo-loads the rupee, or about 8*s.* per ton. It is of very fair quality, weighing from 11 lbs. to 12 lbs. to the bushel of 2625 cubic inches. Seventy or eighty furnaces are engaged during the fine months in smelting, and iron of excellent quality is produced.

The iron here, as everywhere in India, is divided into two sorts, *kachchá* and *pakka;* but these terms have a different signification in each district. At Tendukera *kachchá* iron consists of small blooms of marketable iron, made in a furnace more nearly resembling that of a Catalan forge than any other furnace Mr. H. Blackwell had seen in India. This *kachchá* iron is used for ordinary purposes, and is as good as the *pakka* iron of Chandghur. The *pakka* iron is made in a furnace of a different description, from which it comes as a species of crude steel: it is cut in pieces, re-heated and hammered, whereby it loses its steely character and makes iron of superior quality, which is employed for purposes requiring great toughness and strength. The crude steel is used for making edge-tools, for the points of picks, crowbars, etc., and is of very good quality.

At Tendukera the price of *kachchá* iron is from 3*l.* 3*s.* to 3*l.* 12*s.* per ton; and that of *pakka* iron from 4*l.* 10*s.* to 5*l.* 18*s.* per ton.

"It may, therefore, be said," writes Mr. H. Blackwell, "that iron is made here, by the rudest methods,—without any machinery beyond the bellows and hammer of the workmen,—cheaper than it can be made in England, with every mechanical appliance for facilitating the manufacture."[8] It must, however, be borne in mind that only very small bars are produced by the Hindoos.

The manufacture of iron at Tendukera forms a striking contrast to that of Chandghur, where the *kachchá* quality is a rough mass of iron and slag, that cannot be used until it has gone through a second process of heating and hammering, and has been made into *pakka*, in which state it is sold at 12*l.* 10*s.* per ton; and, notwithstanding this high price, Mr. H. Blackwell states that the smelters are worse paid for their labour than those of Tendukera. The quantity of materials used in making a ton of iron in the two districts is as under:—

	Iron Ore.			Charcoal.		
	Tons.	cwts.	qrs.	Tons.	cwts.	qrs.
Chandghur *pakka* iron	7	10	0	8	5	0
Tendukera *kachchá* iron	3	9	0	3	15	0
Tendukera *pakka* iron	5	3	2	5	12	2

In the Chandghur furnaces part of the fuel used is wood, which, in the preceding statement, is reduced to charcoal at the rate of 5 tons of wood to 1 ton of charcoal.

The great difference in price in these two localities is ascribed

[8] Op. cit. p. 14.

mainly to the quality of the ore; but it is also partly caused by the superiority of the furnaces, and the systematic manner in which the manufacture is carried on at Tendukera, as compared with Chandghur. Moreover, the former town has the advantage resulting from the proper subdivision of labour, mining, charcoal-burning, and smelting constituting distinct occupations. All the iron is purchased from the makers by Banians or merchants, some of whom are men of considerable wealth. The country is supplied with iron, and with articles of all sorts made of iron, for a distance extending in some cases as far as 250 miles.

"Although," as Mr. H. Blackwell observes, "the quantity of iron made at Tendukera is probably much larger than that made at any other town in India, it is ludicrously small compared with the quantities turned out by European works, and amounts to from 20 to 25 tons per week during 8 or 9 months of the year, all the furnaces being stopped during the rains from the difficulty of obtaining charcoal and ore. It was at Tendukera that Captain Franklin some 30 years ago manufactured by the native method sufficient iron for the construction of a suspension-bridge."

With reference to the desirableness of establishing iron-works on the European system in the Nerbudda valley, where ore, charcoal, and coal may be obtained, Mr. H. Blackwell, at the conclusion of his report, says, "I have no doubt that, in the district under consideration, where the mere freight of iron from England will be from *5l.* to *6l.* per ton, iron can be made more cheaply than it can be imported."

It should be borne in mind that even at Tendukera,—notwithstanding the comparatively advanced state of the art,—there was great room for improvement. The mining, we are informed, was carried on in the most unskilful, and, therefore, most wasteful manner; and it can hardly be doubted that the system of charcoal-burning was very defective, if similar to that usually practised in India. Hence it is reasonable to infer that in this locality iron might be produced by the native process and sold at a still lower rate than that above mentioned.

Iron-Smelting in Burma.

I am indebted for the following description to my friend and former pupil, Mr. W. T. Blanford, of the Geological Survey of India.

"Iron is made in several places in Upper Burma, but the largest quantity is said to be obtained from the neighbourhood of a town called Puppa (variously written Paopa, Poulepa, etc.), which lies about 30 miles E. of the river Irawadi, and at the base of an extinct volcanic mountain, in lat. 19° 50′ N., long. about 95° 20′ E. Remains of furnaces are to be seen within the British province of Pegu, near Prome, but I do not know if any iron is yet manufactured.

"The process employed differs from all Indian methods with which I am acquainted in the important particular that no artificial blast whatever is used. I did not see the furnace in operation, but I have no doubt that the following account, given to me by the Burmese work-

men, is correct in all essential particulars, although I cannot answer for the accuracy of the details, especially when weights are specified. The sketches and sections of the furnace are from my own measurements.

"The ore used near Puppa is a brown hæmatite found in small concretionary masses in the gravels which cover a large portion of the country. These concretions generally consist of an extremely ferruginous crust with a nucleus of sandy clay; they are broken into pieces the size of a hazel-nut, and the sand removed by sifting. The fuel is charcoal, of excellent quality: and the process of burning it appears, from the description given to me, to be far superior to any in use among the natives of India. The following is the account of it as given to me by a charcoal burner near Puppa; and I have found the same method in use near Thayet Myo, in Pegu.

"The principal months for burning are January and February, the season for the iron manufacture being from the first-named month till May, and the usual plan appears to be for the workmen to commence by burning a supply of charcoal. During the summer and autumn months they are employed in agricultural operations. Several kinds of wood are used for burning into charcoal, Sâl (*Shorea robusta*) being largely used. Stems from 12 in. to 18 in. in diameter are preferred; those smaller than 3 in. or 4 in. in thickness are not used. The wood when cut is piled into heaps about 12 ft. square and 6 ft. high, the sides being vertical and supported by uprights. These heaps are covered with earth, one opening being left at the base about a foot square, and passing from side to side, but only open at one end. To this, fire is applied by burning a pile of small wood, and when smoke comes out freely from the opposite side the opening is closed, and remains so until the smoke has almost ceased; then it is re-opened and some charcoal removed. The mass re-ignites, the opening is again closed, and is opened again to remove some more charcoal, when the smoke again abates. This is repeated daily for 20 days to a month, during which time the heap continues to burn.

"The only objectionable practice in this method appears to be the use of green wood. It is strange to find so good a system of burning charcoal employed in connection with one of the very rudest methods of iron smelting anywhere in existence.

"No flux is used, as might be expected, and I have already mentioned that no artificial blast whatever is employed; nor does any care appear to be taken in selecting localities where a natural blast might be obtained by making the furnace to face the prevailing wind, for I have seen furnaces in the immediate vicinity of each other facing in several different directions. A steep bank of sandy clay 10 ft. or 12 ft. high is selected for the furnace, which consists simply of a hole of peculiar form, dug in the bank at a distance of 2 ft. or 3 ft. from the edge, which is cut away to a vertical face. Frequently 3 or 4 furnaces surround a small pit. They are about 10 ft. deep, and of an irregular trapezoidal section, the breadth from side to side increasing gradually, from 1 ft. 9 in. in front, and about a foot behind at the top, to 4 ft.

6 in. or 5 ft. at the bottom, while the depth from front to back is 1 ft. 9 in. at the top, 2 ft. about halfway down, and decreases rapidly to 1 ft. at the bottom. The accompanying sketches and sections are drawn to the scale of $\frac{1}{16}$, and give the dimensions of a furnace which I measured. Doubtless there is some variation, but the general form of all the furnaces I saw was the same, and the differences very slight.

"The face of the bank in which the furnace is dug is supported by pieces of wood placed crosswise, and themselves held up by two stout uprights. The lower part of the bank is dug away as shown in the sections; and a rectangular opening about 1 ft. high, and the whole breadth of the furnace, is made at the extreme base, for the purpose of removing the slag and the iron after smelting.

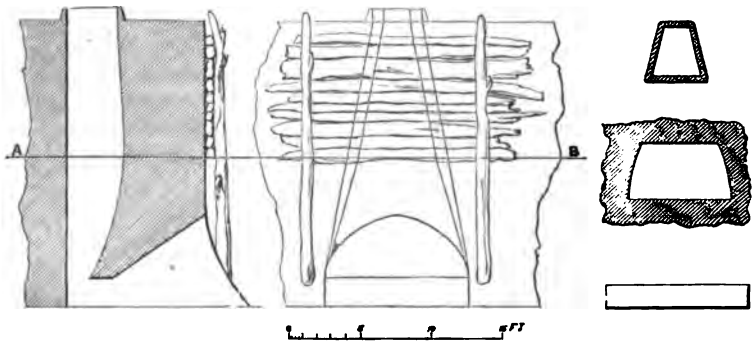

Fig. 11. Burmese Furnace.

"When the furnace is in work, this opening is said to be closed with moist clay, into which about 20 small clay tubes or twyers are built. These twyers are made by plastering moist clay upon rounded stems of wood, cutting them into lengths of about 4 in. each, and burning them. They are about 2 in. in diameter, and are built into the opening in one line about halfway up it. Lighted wood is then thrown into the furnace, and upon it 2 baskets of charcoal, each containing about 25 viss[9] (87½ lbs.); then 3 small baskets of ore, each basket containing about 10 viss (35 lbs.), are added. Upon this one basket of charcoal is thrown, succeeded by 6 small baskets of ore, next another basket of charcoal, then again 3 baskets of ore, and lastly a fifth basket of charcoal.

"When the whole is fairly lighted, and the clay filling the opening at the base thoroughly dried, about 8 or 9 hours from the commencement, the sand forming the hearth of the furnace is scraped away and a space about 4 in. high and the breadth of the furnace is opened to remove the slag. This is closed again, and re-opened every half hour, or more frequently if necessary, until no more slag flows. The smelting is complete at the end of 24 hours; the clay at the base of the furnace

[9] A viss is about 3½ lbs.

is then broken away, and a mass of iron removed. It is of the shape of the hearth, 4 ft. or 5 ft. long, but narrow; and weighs from 5 to 30 viss, the average being 25 viss, or nearly 90 lbs. It is extremely impure, being mixed with slag, pieces of unburnt charcoal, sand, and various impurities, and in this state sells for 6 or 7 rupees[1] the 100 viss (12*s.* to 14*s.* for 350 lbs.). When worked up into knives, etc., the quality is excellent.

"Three men do the work of each furnace. One charge is added immediately after the iron from the preceding smelting is removed, so that generally one piece of iron is obtained every day. Besides the large mass produced by each smelting, a few small irregular fragments are commonly removed with the slag."

Iron-smelting in Borneo.

The natives of this remarkable and luxuriant island have long had the reputation of being skilful workers in iron and steel. They practise the direct process, which they have carried on from time immemorial, and no tradition exists amongst them respecting the first introducer of the art. The following description is from Schwaner's 'Travels.'[2]

Of all the south-eastern parts of Borneo, only the inhabitants of the district *Doeson Oeloe* understand the art of smelting iron and manufacturing it into sword-blades. Accordingly, iron is sent from this district into all parts of the country, and is preferred to English iron, experience having proved that sharper and more durable weapons may be produced from it than from iron of foreign manufacture. The ore employed is clay iron-stone from beds of lignite, of which all the hills of the district are stated to be composed. The strata containing the iron-stone are intersected by the river Barito, and are visible in its deep bed at low water. The natives avail themselves of this circumstance for procuring their supply of ore, which is more or less altered by the action of the water, and in composition approximates closely to brown iron ore (*hydrated sesquioxide of iron*).

The furnace is cylindrical, about 3 ft. 3 in. high, 9 ft. 10 in. in external diameter, and 2 ft. thick. It is built of yellow clay taken from the bed of the river, and is tied round with hoops of bamboo. "It is square in the interior, or is pyramidal, narrowing towards the

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[1] Or rather 6 to 7 tirkals of silver, which are worth about a rupee each. There is no coined money in general use in the King of Ava's territories; silver, of varying degrees of fineness, is the medium of exchange, being valued by weight. Lead, also calculated by weight, is used for small transactions in the capital. (See Yule's Mission to the Court of Ava.)

[2] Travels in Borneo, by Dr. C. A. L. M. Schwaner, during 1843-1847, p. 109. Printed in Dutch. The description is in some respects confused, and is illustrated with a coloured lithograph of the process of smelting. Professor S. Bleekrode, of Delft, in an interesting paper on iron-slags occurring in Holland, states that this plate has been entirely altered and spoiled by the lithographer; and he has illustrated his paper also with a coloured lithograph taken from Schwaner's *original* drawing. My deceased friend, the late Mr. T. H. Henry, who was master of the Dutch language and possessed an extensive knowledge of Metallurgy in all its branches, gave me his assistance in preparing this description. The title of the paper above referred to is, De Ijzerslakken in Nederland en de Ijzerbereiding in Vroegeren Tijd, door Prof. S. Bleekrode. Amsterdam, (circa 1857.)

bottom; and, as far as one can understand the very confused description, the hearth is rectangular, about 1 ft. 7 in. wide, 2 ft. long, and 9 in. deep" (Bleekrode). Each furnace has three clay twyers 11 in. long, and decreasing in width towards the furnace from about 2½ in. to 1 in. There is an opening for the slags to run out, and a cavity is made to receive them.

The blowing machine is a single-acting cylinder of wood, open at the top and closed at the bottom; it is made of the stem of a tree hollowed out, about 5 ft. 6 in. high and 3 ft. in circumference. There is probably a hanging valve opening inwards on one side at the bottom, though no mention is made of the fact. In the wooden blowing machines in use amongst the Chinese there are valves of this kind, which are made wholly of wood, and, nevertheless, fit pretty tight. The blast is conveyed from the bottom of the cylinder through bamboo tubes, about 2 ft. 5 in. long, to the twyers. The piston, of which the stroke is 4 ft., is packed with fowls' feathers, after the custom of the Chinese. Above each cylinder a long bamboo is firmly fixed at one end in a horizontal position, or nearly so; and to the other end a long stick is suspended. At a short distance from this end the piston-rod is connected with the bamboo above, which thus acts like a spring and raises the piston. By pulling down the suspended stick the piston is depressed, so that the machine may be worked exactly like a pump, of which the handle is lifted by a powerful spring. In another account it is stated that the piston-rods are connected with other rods of considerable length, to which weights are fastened, and which are balanced on the cross-beams of the shed covering the furnace, just like the apparatus commonly employed in drawing water from shallow wells.[3]

The clay is mixed with water, carefully tempered with the hands and feet, and freed from stones or other foreign matters. Thus prepared, it is stamped into a cylindrical mould of bark of the dimensions of the furnace. A wooden core seems also to be fixed within, in order to fashion the interior of the furnace. The whole is then left to itself for a month or longer in order to dry well. When sufficiently dry the mould is detached and the furnace bound with hoops of bamboo. Before use the furnace is gradually heated.

The ore preparatory to smelting is interstratified with wood and roasted in heaps during one day, after which it is broken into pieces of the size of nuts and mixed with ten times its bulk of charcoal; and in this state it is charged. The furnace being two-thirds filled with charcoal, the mixture of ore and charcoal is added in sufficient quantity to form a conical heap above the mouth. The piston is worked at the rate of 40 strokes a minute. The slag is tapped off at intervals of 20 minutes; and it is stated that during each tapping, which lasts 5 minutes, the blast is interrupted. Towards the close of the operation the blast is increased. A lump of iron is finally obtained

[3] The Kayans of the North-West of Borneo. By Robert Burns (grandson of the poet). Journal of the Indian Archipelago and Eastern Asia. Singapore, 3, 1849, p. 151.

weighing about 100 lbs. (avoird.): it is taken out at the bottom of the furnace by means of wooden tongs, and removed to a place strewn over with fine slags, where it is worked with wooden mallets nearly into the shape of parallelopipedons. Such a mass is the result of the labour of four men during one day; its commercial value is 2 florins. It retains much intermingled slag, and is divided into 10 pieces, which are repeatedly made red hot and hammered out, until they are sufficiently purified and suitable for forging into sword blades: they lose $\frac{1}{4}$ in weight by this treatment.

From the last statement it would appear that the lump obtained is natural steel, or at least consists of a mixture of steel and malleable iron. I have omitted many of the details in Schwaner's description, some because I do not clearly understand them, and others because they would be superfluous after what has been advanced concerning the Hindoo method of proceeding, to which that of Borneo is in all essential points precisely similar. In the paper by Burns, referred to p. 274, it is stated that "to make the iron either hard or soft as may be required, different sorts of wood are made use of." By this is probably meant that light or dense charcoal, made respectively from light or heavy wood, is employed according as the iron is desired to be less or more steely. If so, the statement is probably correct, as will appear in the description in the sequel of the Catalan furnace.

Iron-smelting in Africa.

The natives of the interior of Africa seem to have attained considerable proficiency in the extraction and manufacture of iron by the direct process. The following interesting description of the process from personal observation was given by the celebrated, but unfortunate traveller, Mungo Park. I insert it without abridgment or alteration:—

"The negroes on the coast being cheaply supplied with iron from the European traders, never attempt the manufacturing of this article themselves; but in the inland parts the natives smelt this useful metal in such quantities as not only to supply themselves from it with all necessary weapons and instruments, but even to make it an article of commerce with some of the neighbouring states. During my stay at Kamalia there was a smelting furnace at a short distance from the hut where I lodged, and the owner and his workmen made no secret about the manner of conducting the operation, and readily allowed me to examine the furnace and assist them in breaking the iron-stone. The furnace was a circular tower of clay, about 10 ft. high and 3 ft. in diameter, surrounded in two places with withes, to prevent the clay from cracking and falling to pieces by the violence of the heat. Round the lower part, on a level with the ground (but not so low as the bottom of the furnace, which was somewhat concave), were made seven openings, into every one of which were placed three tubes of clay, and the openings again plastered up in such a manner that no air could enter the furnace but through the tubes, by the opening and shutting of which they regulated the fire. These tubes were formed

by plastering a mixture of clay and grass round a smooth roller of wood, which, as soon as the clay began to harden, was withdrawn, and the tube left to dry in the sun. The iron-stone which I saw was very heavy, of a dull red colour, with greyish specks; it was broken into pieces about the size of a hen's egg. A bundle of dry wood was first put into the furnace, and covered with a considerable quantity of charcoal, which was brought ready burnt from the woods. Over this was laid a stratum of iron-stone, and then another of charcoal, and so on until the furnace was quite full. The fire was applied through one of the tubes, and blown for some time with bellows made of goats' skins. The operation went on very slowly at first, and it was some hours before the flame appeared above the furnace; but, after this, it burnt with great violence all the first night, and the people who attended it put in at times more charcoal. On the day following the fire was not so fierce, and on the second night some of the tubes were withdrawn, and the air allowed to have freer access to the furnace; but the heat was still very great, and a bluish flame rose some feet above the top of the furnace. On the third day from the commencement of the operation all the tubes were taken out, the ends of many of them being vitrified with the heat; but the metal was not removed until some days afterwards, when the whole was perfectly cool. Part of the furnace was then taken down, and the iron appeared in the form of a large irregular mass, with pieces of charcoal adhering to it. It was sonorous, and when any portion was broken off the fracture exhibited a granulated appearance, like broken steel. The owner informed me that many parts of this cake were useless; but still there was good iron enough to repay him for his trouble. This iron, or rather steel, is formed into various instruments by being repeatedly heated in a forge, the heat of which is urged by a pair of double bellows, of a very simple construction, being made of two goatskins, the tubes from which unite before they enter the forge, and supply a constant and very regular blast. The hammer, forceps, and anvil, are all very simple, and the workmanship (particularly in the formation of knives and spears) is not destitute of merit. The iron indeed is hard and brittle, and requires much labour before it can be made to answer the purpose."*

I have recently received from my friend and former pupil, Mr. J. J. Monteiro, who has during the last few years been engaged in mining and metallurgical operations on the West Coast of Africa, some instruments of iron of native African manufacture, which are extremely creditable. Dr. Livingstone mentions the fact of the extraction of iron and its manufacture into instruments, etc., by the natives in various parts of Africa; and has presented to the metallurgical collection at the Museum of Practical Geology several interesting articles of iron in illustration.

I may here mention incidentally that the same distinguished and veracious traveller states that in 17[illegible]8 iron-works on the European

* Travels in the Interior Districts of Africa. By Mungo Park, Surgeon. London, 1799, p. 283-5.

system were established in Angola, near the confluence of the rivers Luinha and Lucalla. "Near this latter point," he writes, "stand the strong, massive ruins of an iron foundry, erected in the times (1768) and by the order of the famous Marquis of Pombal. The whole of the buildings were constructed of stone, cemented with oil and lime. The dam for water-power was made of the same materials, and 27 ft. high. This had been broken through by a flood, and solid blocks, many yards in length, were carried down the stream, affording an instructive example of the transporting power of water. There was nothing in the appearance of the place to indicate unhealthiness; but eight Spanish and Swedish workmen, being brought hither for the purpose of instructing the natives in the art of smelting iron, soon fell victims to disease and 'irregularities.' The effort of the Marquis to improve the mode of manufacturing iron was thus rendered abortive. Labour and subsistence are, however, so very cheap that almost any amount of work can be executed at a cost that renders expensive establishments unnecessary. A party of native miners and smiths is still kept in the employment of the Government, who, working the rich black magnetic iron-ore, produce for the Government from 480 to 500 bars of good malleable iron every month. They are supported by the appropriation of a few thousands of a small fresh-water fish, called 'cacusu,' a portion of the tax levied upon the fishermen of the Coanza. This fish is so much relished in the country that those who do not wish to eat them can easily convert them into money. The commandant of the district of Massangano, for instance, has a right to a dish of three hundred every morning as part of his salary."[5]

This singular mode of payment will rather surprise our smelters and forgemen, who perhaps would prefer something which in their opinion would be more substantial, even in the fervid climate of Africa.

Iron-smelting in Madagascar.

In this island the direct process is followed, and has evidently attained considerable development. I have acquired my information on the subject from the work of the intelligent and well-known missionary the Rev. William Ellis, author of 'Polynesian Researches.'[6] Iron-ore of excellent quality abounds in the central provinces around the capital; and so rich is it in one of the mountains, Ambohimiangavo, that it is called the Iron mountain. The ore is so abundant at the surface that the soil has seldom been penetrated more than a few feet in depth. The natives have been for many generations accustomed to the use of iron.[7] Their smelting furnaces are always

[5] Missionary Travels and Researches in South Africa. By David Livingstone, etc. London, 1857, p. 402.

[6] Three Visits to Madagascar during the Years 1853, 1854-1856. By the Rev. William Ellis. London: John Murray, 1858, p. 264.

[7] My friend, Mr. Crawford, the well-known former Governor of Singapore, informs me that the Malagasy word for iron is nearly the same as the Malay word; and for this and other reasons he is of opinion that the art of smelting iron in Madagascar is of Malay origin. This art, he further informs me, is generally known and practised throughout the Indian Archipelago.

fixed near a stream; and the ore when collected in large pieces is broken small, and freed from earthy matter by frequent washings. The walls of the furnaces, which are usually sunk 2 or 3 ft. in the ground, are made of stones, and covered outside with clay. A small quantity of fuel is kindled at the bottom of the furnace, which is then filled with ore, either mixed with charcoal or in alternate layers, after which it is covered at the top with a thick coating of clay. The blast is supplied by two pairs of pistons, working in wooden cylinders, generally a part of a tree hollowed out. From the bottom of each cylinder a tube formed by a bamboo, or an old gun-barrel, is inserted into a hole through the stones around the furnace. After the contents of the furnace have for some time been kept at a white heat it is left to cool, and when opened the iron is found in lumps at the bottom. In this state, as well as after having been reheated and hammered out into bars or rods, it is taken to the government stores, or to the market for sale.

The forge of the native smith is a very simple affair. The earthen floor of his house forms the hearth for his fire, which is kept together by three or four stones. The bellows consist of two wooden cylinders with pistons, similar to those which supply the blast furnace. The anvil, which is about 6 in. square and 6 high, is let into a thick piece of wood fixed in the ground, with the water-trough, tongs, hammers, and other tools near it. The smith squats on a board on the floor, and his assistants sit or stand opposite to him with sledge-hammers in their hands ready to strike when required.

Mr. Ellis has illustrated his description with an engraving, which, though deficient in working details of interest to the metallurgist, doubtless presents a faithful general impression of Madagascar iron-works.

Catalan Process.

This process derives its name from the province of Catalonia in the North of Spain, where, probably, it was first introduced into Western Europe. Until a recent period it was extensively practised in the South of France, especially in the department of Ariége, which is separated from Catalonia by the Pyrenees. An establishment containing furnace and other necessary accessories is termed "forge Catalane" by the French, and accordingly in the succeeding pages I shall use the term Catalan forge in the same sense. The literature on this subject is pretty copious; but I have chiefly derived my information respecting the process from the elaborate treatises of Richard and François.[a] I shall avail myself freely of the labours of these authors, and shall not hesitate to introduce literal translations of entire passages

[a] Études sur l'art d'extraire immédiatement le fer de ses minerais sans convertir le métal en fonte. Par T. Richard. 4to. pp. 370, with folio atlas of 9 lithographic plates. Paris, 1838. Recherches sur le gisement et le traitement direct des minerais de fer dans les Pyrénées, particulièrement dans l'Ariége. Par M. Jules François. 4to. pp. 404, with atlas of 10 copper-plates. Paris, 1843.

or even paragraphs from their works. A Catalan forge is a very small and insignificant thing compared with a modern iron-work. In 1845 I was at Cierp, in the Pyrenees, and passed by the forge de Guran, situate at a short distance up the valley leading to Bagnères de Luchon, without at first being aware of its existence, though actually in search of it.

A Catalan forge consists essentially of a furnace, a blowing machine, and a heavy hammer; and if the blowing machine called the "trompe" be employed, the forge should be erected in a locality where a fall of water from a considerable height, from 11 to 12 feet at least, may be secured. Brown hæmatite not too compact is the ore usually preferred, but spathic ores and compact hæmatite, brown or red, are also treated. The fuel is invariably charcoal. The choice of a site must be determined with reference to local circumstances; and some of the Pyrenean valleys are in all respects suitable. If a fall of water from a considerable height cannot be obtained, the trompe must be replaced by some other blowing machine.

Historical documents exist which prove that the direct process of extracting iron was practised in the French Pyrenees so long ago as 1293, and has been ever since in operation.[1] But it is probable that it was established in the same locality long anterior even to that remote period. Originally it appears to have been conducted on a very small scale, like that of the native Hindoo iron-smelters of the present day. In 1823, at Bielsa, in Aragon, in the Spanish Pyrenees, nearly opposite to Bagnères de Luchon, some charcoal-burners discovered in a forest of silver firs a small circular iron furnace only $0^{m}\,65$ (2 ft. 1·59 in.) high. The lower part or hearth was cylindrical up to the height of $0^{m}\,30$ (about 11·81 in.) and then terminated in an inverted truncated cone; its diameter was $0^{m}\,36$ (14·25 in.) at the lower, and $0^{m}\,48$ (1·69 in.) at the upper part; it had two twyer beds at $0^{m}\,30$ (11·81 in.) from the bottom. Near the furnace were found two crude lumps of iron, in the state in which they appeared to have been taken out, and which weighed from 14 to 16 kil. (30·9 to 35·3 lbs.) According to tradition the blast in these furnaces was produced with bellows of skin worked by hand. Accumulations of ancient slags are met with at high elevations in the Pyrenees, far from any water-course, and which, doubtless, were urged by a blast produced by manual labour.[2]

The furnace in use early in the 17th century in the Spanish provinces of Navarre and Guipuzcoa, and on the French frontier on the bank of the Bidassoa, was a shallow oval cavity or hearth wider at the top than the bottom, so that it had the form of a flattened inverted truncated cone. There was only one twyer, which projected downwards and inwards over the middle of one of the long sides of the oval. The furnace was of masonry, bound with hoops of iron, and fixed in a copper vessel to protect it from wet. François considers this as the transition stage from the primitive to the modern Catalan furnace.[3]

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[1] For the following historical notices I am indebted to the compendious work of François.
[2] François, p. 317.
[3] Ibid.

From the middle of the 17th century in the department of Ariége the furnaces were made more or less rectangular and wider at the upper part in order to increase the charge of ore, and for a long period the lower part continued cylindrical. The discovery not very long ago of the remains of furnaces in one of the high valleys in the French Pyrenees indicates that at the beginning of the 18th century the furnaces had sensibly the same form as those of modern construction in the valley of Tech (Wallespire) in the Eastern Pyrenees. They were quadrangular and rounded off at the angles, 0^{m} 43 (1 ft. 4·93 in.) wide, 0^{m} 49 (1 ft. 7·29 in.) deep, and 0^{m} 52 (1 ft. 8·48 in.) high. Each operation lasted 5 hours, and yielded from 60 to 80 kil. (132 to 176 lbs.) of bar iron. During a long period the twyer continued to be fixed at from 0^{m} 23 to 0^{m} 32 (9 ft. 05 in. to 12·60 in.) from the bottom, with an inclination of from 35° to 40° with the horizon; and it was only towards the end of the 18th century that it was raised to the height of 0^{m} 52 (1 ft. 8·48 in.), having still an inclination of 35°. By this alteration the yield per furnace was increased to from 120 to 150 kil. (264·6 to 330·7 lbs.) of bar iron.[4] This record is extremely instructive, as showing what important practical results may sometimes be produced by very slight changes. In studying the history of the Metallurgy of Iron in the sequel we shall meet with far more striking illustrations of the same truth. Indeed, it may confidently be affirmed that in one instance an innovation apparently of the most trivial kind has influenced the destinies of the human race. I allude to the introduction of the *hot blast*, of which the marvellous effects will be fully detailed hereafter. The moral which the metallurgist should learn from facts like these is never to disregard changes because they may at first appear small and unimportant.

The blast in the early furnaces was produced by two bellows working alternately; and, according to François, it was not until the end of the 17th century that the *trompe* was first employed in the Pyrenees.

The hammer was small, and worked by man-power. It was constructed on a similar principle to that presently to be described.

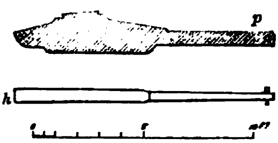

Fig. 12. Ancient Biscayan Hammer.

Annexed is an engraving of an old Biscayan hammer, still preserved. It is made of iron, and acted only by its weight; it moved up and down on a pivot at *p*, and was raised by lifting the head *h*. Such hammers weighed from 1200 to 1600 kil. each, *i. e.* about 1¼ ton.

Composition of ore.—All the ore treated in the forges of the department of Ariége is derived from the mines of Rancié, a mountain in the little valley of Sem, at about 2000 metres from Vicdessos. The ore occurs in secondary limestone resting on granite. These mines are of great antiquity. The following analyses of ores which have been treated with advantage in the Catalan furnace in the Pyrenees are inserted by way of illustration:—

[4] Op. cit. p. 319.

	1.		2.	3.
Sesquioxide of iron......	62·474		65·50	64·00
Peroxide of manganese	6·213		3·00	6·20
Lime........................	2·790		5·00	3·50
Magnesia..................	0·545		0·45	0·80
Alumina	1·014		1·30	1·20
Silica	14·715		11·40	10·50
Water	12·112	Loss by calcination	13·20	14·50
Loss	0·137			
	100·000		99·85	100·70
Iron per cent.	43·752		45·87	44·82

No. 1. By Richard.[5] Average composition of the usual charge of 12 quintals (487 kil.) of ore, consisting of lumps and small ore (*greillade*), during the years 1833, 1834, 1835. Nos. 2, 3. By François.[6] No. 2. Average composition deduced from two analyses of the mixture of ores taken in 1841 from the forges of Vicdessos, Niaux, Lacour, and Mas-d'Azil. No. 3. do., in 1842. According to François these varieties of ore gave a yield which in some establishments amounted to 32·78 %, and was pronounced *good*, though the loss of iron was not less than from 12 to 13 %. On inspecting the foregoing analyses, it will be perceived that there must be a considerable quantity of *free* silica.

The hydrated oxides which are pulverulent, porous, or but slightly compact, may be directly introduced into the furnace; but spathic ores or such as contain much carbonate of lime, and the rich compact brown hæmatites, require a preparatory treatment. For compact hydrated oxides or slightly calcareous varieties, simple calcination suffices; but anhydrous and siliceous oxides should be disaggregated by heating to redness, quenching in water, and afterwards leaving them exposed to the air during some months. François states that by this means the ores become slowly and in a very great degree hydrated, especially if the process of heating, quenching, and exposure be repeated two or three times.

Calcination may be effected in square, circular, or oval kilns of brick from 1^m 70 to 2^m 30 (5 ft. 6·9 in. to 7 ft. 6·55 in.) high, and from 2^m 00 to 2^m 50 (6 ft. 6·74 in. to 8 ft. 2·43 in.) in internal diameter. From 300 to 400 metrical quintals (from 30 to 40 tons) of ore are piled in alternation with layers of wood, 6 stères (1 stère = 1 cub. metre) if *dry*, and 7·50 if *green*. In the former case calcination will last 2, and in the latter 3 days.[7] Care must always be taken so to moderate the temperature as to prevent "*coagulation*," that is, incipient fusion of the ore, whereby the object of the process—which is that of loosening the substance of the ore and rendering it pervious to the gases of the furnace—would be entirely defeated.

François states that he obtained excellent results from an ore containing iron-pyrites by gently roasting it two or three times, and afterwards leaving it exposed to the air and the action of percolating water.[8] The sulphur is thus in great measure removed in the state of sulphate of iron.

[5] Op. cit. p. 107. [6] Op. cit. p. 138. [7] Op. cit. p. 258. [8] Op. cit. p. 256.

According to Richard every iron ore containing about 50°/₀ of iron and free from noxious ingredients, which occurs in a compact state so that it may be procured in lumps, and especially is either porous or may be rendered so by roasting, is adapted for treatment by the direct method. But of all ores, none are better suited for this method than compact brown hæmatites, which lose their water of combination by heat, and become more or less disintegrated.

Furnace.—It consists simply of a four-sided cavity or hearth (*creuset*). It is contained within a building, and is always placed against one of the main walls, from which it is separated only by a little wall,

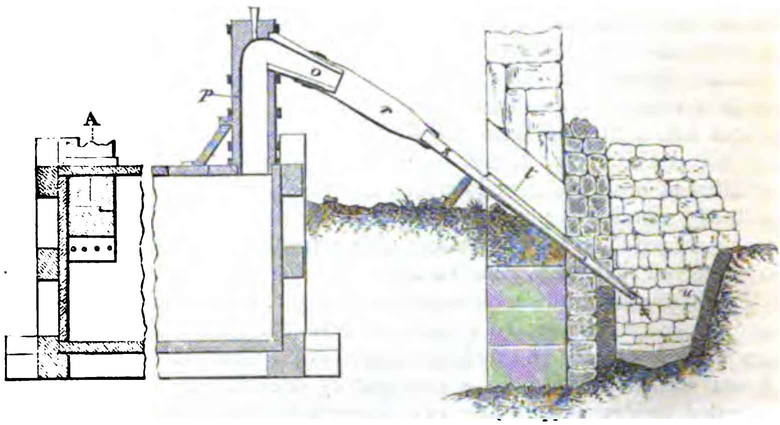

Fig. 13. Trompe and Furnace. Longitudinal vertical section.

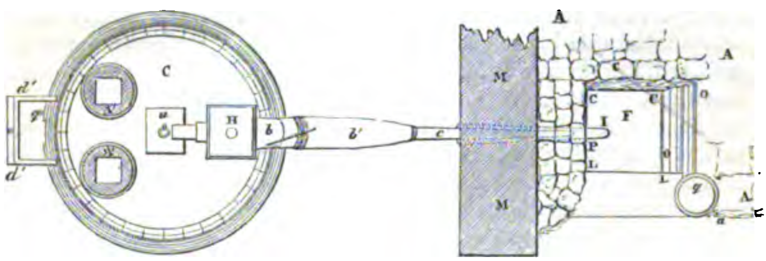

Fig. 13 *a*. Tine and Furnace. Plan.

v, fig. 13 (*piech d'el foc*). It varies in dimensions not only in different forges, but even in the same forge at different times; for although the managers may insist upon the importance of exact proportions, yet it is in reality built by rule of thumb, and has frequently been found to deviate considerably from the dimensions prescribed.[9] The four sides will be designated by the numbers 1, 2, 3, 4 respectively, counting towards the left. No. 1 is the front side, L L, fig. 13 *a* (*la main, le laitairol*); No. 2 is the left side, on which the blast enters, P

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[9] Richard, p. 230.

(*côté des porges*); No. 3 is the back, C C (*la cave*); and No. 4 is the right side, O (*l'ore ou contrevent*).

Side No. 1. It is vertical, and generally formed of two strong pieces of iron,[1] 0m 07 to 0m 08 (2·76 in. to 3·15 in.) thick, 0m 15 to 0m 20 (5·91 in. to 7·87 in.) broad;[2] they sink into the ground below the floor from about 0m 20 to 0m 25 (7·87 in. to 9·84 in.), and rise above the floor 0m 52 (1 ft. 8·48 in.). Between these two pieces a space is left, about 0m 06 (2·36 in.) wide,[3] which below receives another piece of iron (*le respalme*). This piece does not sink quite so much below the floor level as the other two pieces, and it only rises to the height of a few centimetres (0m 01 = 0·39 in.) above the floor: it serves as a fulcrum for an iron bar which is used in raising the lump of reduced iron from the bottom. All the rest of the space is filled up with clay or other suitable mixture (*terre à fourneau*). It is in the lower part of this space that openings are made for the escape of the slag. Such an opening (*le chio*) is shown in fig. 14. Upon the upper faces of the two

Fig. 14. View of a Furnace, showing the mode of raising up the lump of reduced iron or *massé*. Drawn by Justyne from a sketch by Richard.

vertical pieces of iron forming No. 1 (*laitairoles*) is placed horizontally a strong piece of iron (*la plie*), which passes into the wall on the left, and is supported by the opposite wall on the right. It should be firmly fixed, as it is exposed to rough treatment during the working of the furnace; on the left it is let into the *piech d'el foc*, and on the right it is kept in its position by an old hammer-head, see fig. 14, or

[1] When the term iron is used, *wrought* and not *cast* iron is intended.

[2] In reducing the French to English measures small fractions of an inch have been neglected.

[3] François gives the width of the space as 0m 19 (7·48 in.); and in other dimensions he does not quite agree with Richard.

heavy round stone hooped with iron, see fig. 19, *q*. On the outside of the *plie* two, and sometimes three, wide bands of iron are fixed, so as to form a plane (*la banquette*) inclining towards the interior of the hearth, of which the acute angle never exceeds 10°; and the total length from front to back is generally about 0^{m} 40 (1 ft. 3·75 in.). The width of this plane is about 1^{m} 15 (3 ft. 9·28 in.) on the outside, and 0^{m} 805 (2 ft. 7·52 in.) on the inside of the furnace. The space between the *laitairoles*, *respalme*, and *plie* is stopped with clay, in which openings may be made to tap off the slag.

Side No. 2. It is composed, *below* the twyer, of rectangular pieces of iron (*porges*) placed one over the other, forming a vertical wall; and, *above* the twyer, of rough stone-work (*parédou*), see fig. 13. The cross-section of these blocks is from 0^{m} 12 to 0^{m} 15 (5 in. to 6 in.) on the side. The twyer rests upon the uppermost block of iron, and passes through a small arched opening in the *piech d'el foc*, about 0^{m} 50 (1 ft. 7·69 in.) from the bottom of No. 2 (*les porges*).

Side No. 3. It consists wholly of stone-work set in clay, and in this respect differs from the other three sides. It is not vertical, like No. 1, but always inclines backwards about 9° from the perpendicular, from its base to the top of No. 4, whence it rises vertically. Its base is sensibly parallel to that of No. 1, and the distance between the two sides at this part is 0^{m} 60 (1 ft. 11·62 in.). Its total height varies from about 1^{m} 50 to 2^{m} (from 4 ft. 11·06 in. to 6 ft. 6·74 in.). In the course of working this side becomes more or less hollowed out; and, according to François, it is purposely made of a material which will allow the hearth to be extended in this direction under the influence of the blast.[4]

Side No. 4. It is composed of several strong pieces of iron resting against stonework externally. The upper ones may be made of cast-iron. It is curved, and inclines considerably outwards, especially at the upper part. At the base it is sensibly parallel to No. 2. The distance from the bottom of No. 2 to that of No. 4 is about 0^{m} 61 (2 ft. 01 in.). The bottom of the furnace is very nearly a rectangle, of which Nos. 2 and 4 always exceed the other two sides by a few centimetres (0^{m} 01 = 0·39 in.). The furnace should not be quite square with the wall M M, see fig. 19, but should be turned slightly round towards the right, so that the end of No. 1 at the bottom is brought about 0^{m} 03 (1 ft. 18 in.) forward, and the end of the bottom of No. 2, where it joins No. 3, is advanced about the same distance towards the right. The ends of the pieces of iron forming three sides of the furnace pass in a greater or less degree into the sides with which they are respectively in contact, thus giving solidity to the whole structure.

The bottom of the furnace is formed of a refractory stone, such as granite, gneiss, mica-schist, sandstone, or even limestone. It must not be too large to admit of its being taken out and replaced by a fresh one. Its upper surface should be flat, or by preference somewhat concave. These stones last from 6 hours to 3 or 6 months, and sometimes longer; but this depends on the skill of the furnace man.

[4] Op. cit. p. 284.

The furnace should rest on a solid and dry foundation, and be secured from inundation by floods, which are apt to occur in mountainous valleys. The bottom stone rests upon a bed of pounded slags and clay brasque, from 0^{m}40 to 0^{m}58 (from 1 ft. 3·75 in. to 1 ft. 10·84 in.) in thickness; and below this is a large stone, generally an old mill-stone.

None of these furnaces are provided with chimneys, but there is a hole 4 or 5 metres square (13 ft. or 14 ft.) in the roof above for the escape of the gaseous products of combustion.

Twyer.—It is a somewhat flattened conical tube of copper, 0^{m}48 (1 ft. 6·90 in.) long, formed by simply bending a plate and bringing the edges in contact without soldering them together. At its wide end, and on its upper surface, the edges of the plate of copper, out of which it is formed, are separated by a considerable space, and gradually approximate till they meet at 0^{m}75 (2 ft. 5·53 in.) from that end: the section of the tube at this point is a little ellipse, of which the axes are 0^{m}10 and 0^{m}08 (3·94 in. and 3·15 in.). At the wide end its vertical or short diameter is 0^{m}13 (5·12 in.), and its transverse, or long diameter, is 0^{m}23 (9·05 in.). The thickness of the copper forming the twyer increases from about 0^{m}002 (0·08 in.) at the wide end to 0^{m}008 or 0^{m}013 (0·31 in. to 0·51 in.) at the small end. The small end is slightly bevilled, forming an upper lip, projecting over the lower one from 0^{m}01 to 0^{m}02 (0·04 in. to 0·08 in.). The orifice at this end is a sort of imperfect rectangle, of which the great side is horizontal, and is about 0^{m}042 (1·66 in.), the other being about 0^{m}033 (1·30 in.) in length. But it is hardly necessary to remark that the dimensions and form of the orifice are liable to considerable variation in the course of working. The inclination of the long axis of the twyer with the horizon is about 40°. The projection of the twyer into the furnace, measured from the upper lip in the line of the twyer to the wall on No. 2 side, is about 0^{m}225 (8·86 in.): with *strong* charcoal it is made to project further than with *light* charcoal.[5] The direction of the twyer is almost always more or less towards side No. 3. A vertical plane passing through the axis of the twyer does not bisect the bottom into two equal parts, but invariably approximates nearer to side No. 3 than side No. 1.

The distance between the nozzle of the blast-pipe and the orifice of the twyer ranges from 0^{m}30 to 0^{m}53 (11·81 in. to 1 ft. 8·87 in.). When the blast-pipe does not penetrate far enough into the twyer, the latter, being no longer sufficiently cooled, is liable to be melted, especially if the blast is feeble.

A considerable quantity of air (often with the velocity of 2^{m}00 per second) may enter the furnace through the space between the twyer and the blast-pipe, being drawn in by the current of air from the latter.

Trompe.—With one or two exceptions this was the only kind of blowing machine employed in the Catalan forges of the Department of Ariége.[6] It is said to have been invented in Italy in 1640. It is

[5] François, p. 286. [6] Richard, p. 169.

a simple, effective, and ingenious contrivance for producing a continuous and equable blast; but its use is restricted to localities where a fall of water from the height of several yards can be obtained.

It consists of a strong cistern of wood (*paicherou*) capable of holding about 10 cubic metres, or about 10 tons of water, B, figs. 15, 16; of a wooden case, or wind-chest, C; and generally of two vertical pipes or trees (*arbres*), A A, connecting B and C together.

The trees A A are contracted, or throttled, at the top by two flat pieces of wood, *b* (*étranguillons*), which are kept in their position by transverse bars of wood, *c*, and supported by wedges on the outside: see fig. 15. A narrow rectangular *throat*, *b*, is thus formed at the top of each tree; and immediately below this, in the sides of the tree, are two similar, rectangular, and opposite holes, or aspirators, *e e* (*aspirateurs*), which incline inwards and downwards at an angle of 40° or 50° with the horizon.

The wind-chest, C, is a trapezoidal wooden case; in its upper and broad end the trees are inserted, and in the opposite or narrow end a quadrangular vertical pipe, *p* (*l'homme*), is fixed. To this is attached a muzzle, *o* (*burle*), which is connected by means of a sheepskin tube, *r* (*bourec*), with the blast-pipe, *s* (*canon de bourec*), generally of iron, but sometimes of copper. String is tied round the joints, and twisted tight by a little lever of wood: see fig. 19. Behind the pipe, *p*, there is an opening to allow a man to pass into the interior to effect repairs. It is closed with a lid, which is kept in its place by an inclined prop resting against *p*. At the bottom on one side is an opening, *w*, for the exit of water, and it is stated that trompe carpenters have considerable difficulty in regulating the size of this opening so that the proper quantity of water may escape. But, as Richard remarks, this difficulty might readily be overcome by adjusting a sliding door to the opening in question. There is a strong platform of wood extending from side to side, *l* (*banquette*), immediately under the trees. In the upper surface of this platform a flat stone, or plate of cast-iron, *m*, is inserted. This is intended to protect the wood from the wear which it would suffer if the water falling from a considerable height through the trees were allowed to impinge directly upon it.

Operation of the trompe.—On raising the wedges, *d*, water rushes down the trees, A A, when air is immediately drawn in through the holes, *e e*, and thus the wind-chest, C, is supplied with a mixed and continuous current of water and air. The water escapes below through the side opening, *n*, and the air above through the pipe, *p*. It is obvious that C should always contain a stratum of water of sufficient depth to close the opening, *n*, for otherwise air as well as water would escape from it. Fig. 18 shows plainly how this condition may be secured on the principle of the common bird-cage fountain. The separation of the water from the air is greatly promoted by the platform, *l*. There is reason to believe that a very large amount of air does sometimes escape along with the water.[7]

[7] Richard, p. 223.

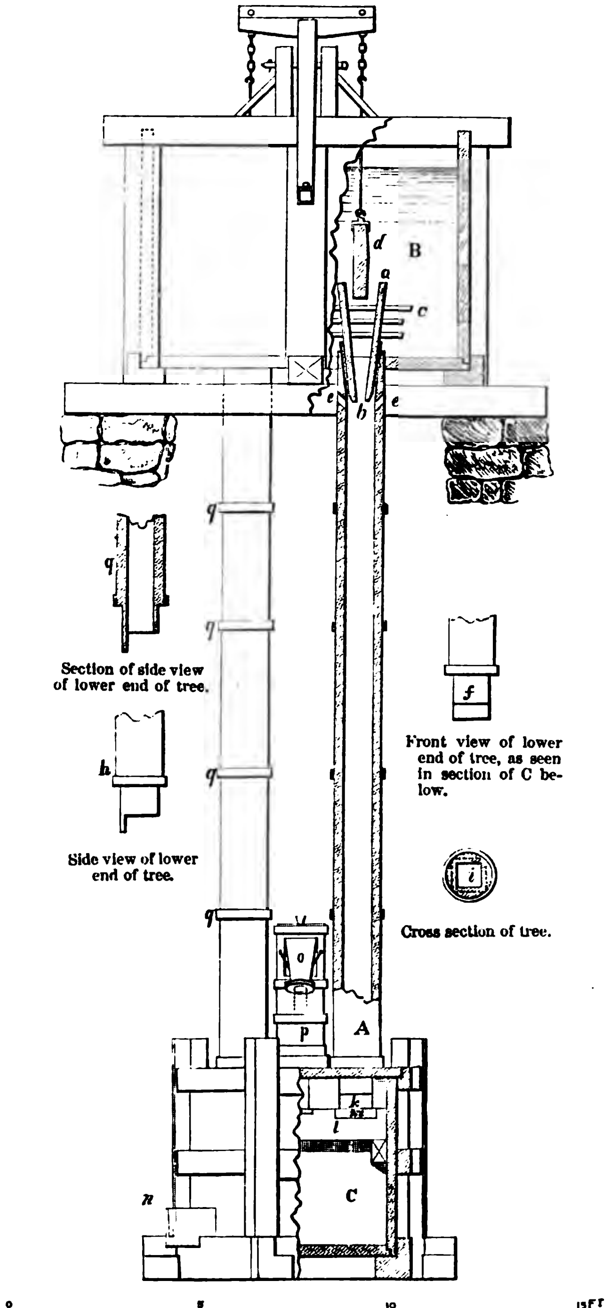

Fig. 15. Trompe. Front elevation. All the woodcuts are copied from Richard's plates of the trompe at Montgaillard (Ariége). The right half is shown in section.

Special details of construction.—The trees, A A, are made as follows:—A straight stem is sawn longitudinally into two equal parts, and the flat side of each of these is hollowed out. The two halves are then put together in their original position, firmly fastened by iron rings, and well caulked: see *q q q q*, fig. 15. The cross section of the cavity of these trees is generally square, 0^{m} 189 (7·44 in.) on the side when the fall is very high, as at Montgaillard, but 0^{m} 216 (8·50 in.) when the fall is feeble. Some trompes have trees with cylindrical cavities.

The aspirators, *e e*, are 0^{m} 08 (3·15 in.) wide by 0^{m} 05 (1·97 in.) deep. In the trees of the trompe represented in fig. 15 were other aspirators, 2^{m} 10 (7 ft. 0·68 in.) below the upper ones; these were square in section, 0^{m} 04 (1·58 in.); water frequently flowed back through them, and always with intermittence. Richard states that according to his

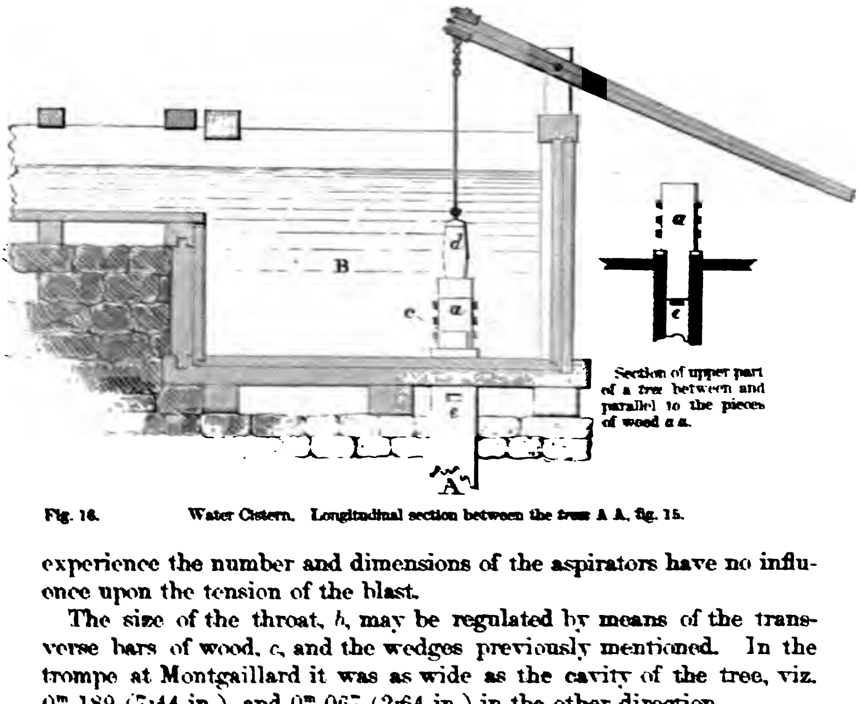

Fig. 16. Water Cistern. Longitudinal section between the trees A A, fig. 15.

experience the number and dimensions of the aspirators have no influence upon the tension of the blast.

The size of the throat, *h*, may be regulated by means of the transverse bars of wood, *c*, and the wedges previously mentioned. In the trompe at Montgaillard it was as wide as the cavity of the tree, viz. 0^{m} 189 (7·44 in.), and 0^{m} 067 (2·64 in.) in the other direction.

The amount of blast is determined by the quantity of water which is allowed to flow through the trees, and this is regulated by raising or lowering in a greater or less degree the wedges, *d*, suspended from a lever by a chain: see fig. 16. This lever is worked by a long chain extending close to the furnace, so that during the process the workmen may be enabled conveniently to modify the blast according to circumstances.

Considerable importance is attached by trompe carpenters to the construction of the lower ends of the trees, which is shown in *g*, *h*, *f*, fig. 15.

The wind-chest should have a solidly constructed framework of wood. The internal dimensions of that represented in fig. 17 are as follow:—3^{m} 09 (10 ft. 1·65 in.) long, 1^{m} 51 (4 ft. 11·45 in.) wide at the broad end, 0^{m} 395 (15·55 in.) at the narrow end, and 1^{m} 32 (4 ft. 3·97 in.) deep. The cross section of the interior of the pipe, *p*, is square, 0^{m} 20 (7·87 in.) on the side. The interior of the muzzle, *o*, is quadrangular where it joins *p*, 0^{m} 18 (7·09 in.) by 0^{m} 20 (7·87 in.), and circular at the other end, 0^{m} 12 (4·73 in.) in diameter. The blast-pipe is conical, and 0^{m} 037 (1·46 in.) in diameter at its narrow end.

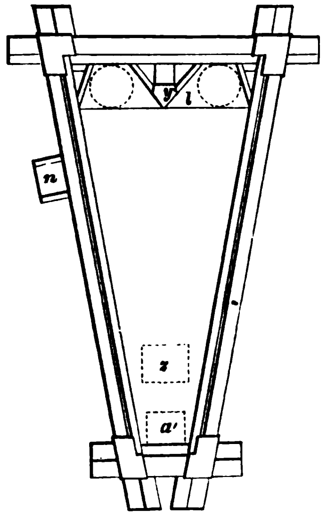

Fig. 17. Trompe. Plan. The top is removed. The dotted circles show the position of the trees, *s* that of the man opening, and *a'* that of the pipe *p*. By mistake, the black lines are on the wrong side.

There is a modern and now generally adopted modification of the trompe, called *tine* by the French, in which the wind-chest is circular, like a barrel, and is more easily constructed than the trapezoidal wind-chest: it is represented in figs. 18 and 19, which will be intelligible without any further description. The blast of the *tine* is said to be *wetter* than that of the old trompe, in which the distance is much greater between the lower ends of the trees and the air exit pipe (*l'homme*); the reason of this appears pretty obvious. There are also variations in the mode of introducing the air into the trees. At Villeneuve-d'Olmes the arrangement shown in fig. 20 was adopted instead of the usual aspirators.[8]

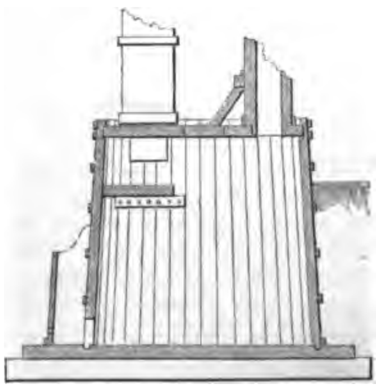

Fig. 18. Tine. Vertical section through the centre.

The tension of the blast is measured by a simple mercurial syphon gauge of glass, the lower leg of which is contained in a wooden plug which fits into a hole at the top of the pipe, *p*: see fig. 15. A graduated scale is attached to the instrument, each degree corresponding to a column of mercury, 0^{m} 004512 (0·18 in.) in height.[9] According to Richard no machine produces a blast of such constant tension as the trompe, the mercury appearing as though it were congealed in the gauge. The degree of

[8] Richard, p. 178. [9] Ibid., p. 181.

tension depends chiefly on the height of the fall of water. In the department of Ariége trompes are met with from 9ᵐ 00 to 10ᵐ 00

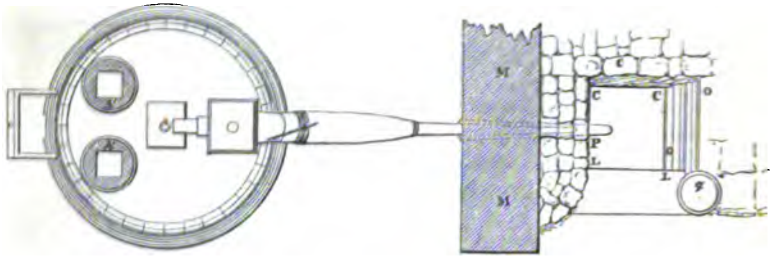

Fig. 19. Tine and Furnace. Plan.

(29 ft. 6·33 in. to 32 ft. 9·70 in.) high; but they generally are only from 7ᵐ 00 to 8ᵐ 50 (22 ft. 11·59 in. to 27 ft. 10·65 in.) high. A well constructed trompe with such falls may give a blast having a maximum tension of 0ᵐ 0855 (3·37 in.), and sometimes even 0ᵐ 0945 (3·72 in.) of mercury, *i.e.* from about 1½ to 2 lbs. pressure to the square inch. On account of the nature of the ore, and in order to economise fuel, good trompes are now (1843) so regulated that the maximum tension of the blast never rises higher than 0ᵐ 0675 (2·66 in.) of mercury, *i. e.* about 1¼ lb. to the square inch.

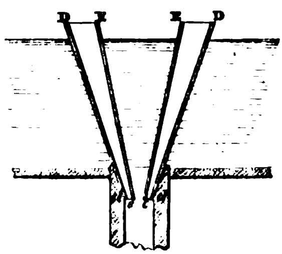

Fig. 20. Another method of introducing air through the tubes D E, E D, called Trompilles.

The pressure of water upon the *throat* of the *trees* appears to have much less influence in increasing the tension of the blast than the height of the trees. Richard has seen trompes which had only a column of water of 0ᵐ 73 (2 ft. 4·7 in.) above the throat, and yet produced a blast having a tension of 0ᵐ 0812 (3·19 in., about 1½ lb. to the square inch) of mercury; while other trompes which had a column of water of 2ᵐ 00 (6 ft. 6·74 in.), could only produce a blast having a tension of 0ᵐ 0677 (2·57 in., about 1¼ lb. to the square inch) of mercury, the dimensions of the throats and sectional areas of the blast-pipes being the same in both cases.[1]

The tension of the blast is sensibly proportionate to the amount of water expended, except when the latter is much reduced beyond the limits occurring in practice.

The amount of water expended being the same, the dimensions, form, and nature of the throat influence the tension.[2]

The following observations of Richard on the trompe deserve attention. There were four aspirators towards the middle of the tree of a *tine*, from which water was ejected at intervals. In each was fixed a bent glass tube, one end of which communicated with the interior of

[1] Op. cit. p. 223. [2] D'Aubuisson.

the tree, while the other plunged into water contained in a glass vessel. Bubbles of air escaped intermittently from the ends of the tubes immersed in water. Hence it was supposed that by closing these aspirators the tension of the blast would be increased; but this was not found to be the case in the slightest degree. A similar experiment was made upon another trompe, and with the like results.

Experiments were then made upon the uppermost aspirators. In one of these one end of a bent glass tube was adjusted in the manner above described. The water rose $0^{m}\,02$ (0·79 in.) in the leg in the glass vessel. One of the aspirators was closed, but without causing any change, the water still rising $0^{m}\,02$ in the glass tube, and the mercurial gauge showing no sign of diminished tension. It was also found that the level of the water remained constantly at $0^{m}\,02$, whether the throats were opened to the full or closed so as to reduce the tension of the air in the wind-chest to $0^{m}\,02707$ (1·07, about $\frac{1}{2}$ lb. to the square inch) of mercury, notwithstanding the tension increased in proportion as the throats were opened.

Richard asserts that the tension of the blast is somewhat diminished when the water becomes muddy, as after a storm.

Advantages and disadvantages of the trompe.—It may be constructed and kept in order at a small cost compared with blowing cylinders; and it produces a remarkably equable and an easily manageable blast. On the other hand, the air constituting the blast of the trompe is not only always saturated, or nearly so, with moisture, but contains fine particles of water in mechanical suspension; and the amount of water which is thus introduced into the furnace along with the air is a serious and inherent defect of this kind of blowing machine. Water often *sweats* through the skin tube, or *bourec*, and runs down the blast-pipe into the furnace; but this ought not to be the case, and indicates a defect in the construction or in the working of the trompe. The proportion of mechanically suspended water may be considerably increased if the water in the wind-chest be allowed to rise above the *banquette*, or the distance between the lower ends of the *trees* and the *air-exit pipe* be much diminished. This finely divided water may be carried by the air to a great distance: thus D'Aubuisson employed a trompe to ventilate a mine, and conveyed the air through a conduit pipe along a level to the distance of 387 metres (about 423 yards); and although it passed through two elbows of 90° and two others of 135°, and ascended considerably all the way, yet currents of water were observed to escape from the end of the pipe.[3]

Theory of the trompe.—Venturi, in 1800, accounted for the blast by the motion which he supposed the falling stream of water communicated to the surrounding air in contact with it. Thibaud and Tardy give the following explanation: the water in its descent through the trees increases in velocity, diminishes in horizontal sectional area, and

[3] Expériences faites sur la trompe du ventilateur des mines de Rancié, suivies de quelques observations sur les trompes en général. Par M. D'Aubuisson. Ann. d. Mines, 2. s. 4, 1828, p. 244.

leaves a vacuum, into which air rushes through the aspirators, and is carried down by the water.[4] Richard confesses his inability to present a satisfactory theory. In 1848, Magnus, Professor of Physics in the University of Berlin, affirmed that the true physical cause of the rushing down of the air was still quite unknown.[5] This distinguished philosopher, however, is led from his experimental researches on the motion of liquids to conclude that in the trompe the same action occurs as when water is poured into a glass, and bubbles of air become entangled in, and are carried down by, the water. If the reader will make this simple experiment and attentively observe the result, he will, probably, be surprised at the large volume of air which will thus pass *deep into* the water in the receiving vessel. Magnus has described some very interesting experiments bearing upon this subject; but for a record of these I must refer the reader to the original paper.

Efficiency of the trompe.—In a well proportioned and well made trompe the *effect* may generally be estimated as at least $\frac{1}{10}$ of the *power*, *i.e.* the force represented by the fall of a given quantity of water, from a given height, in a given time, being 1, that represented by the blast produced by this water in the same time is only 0·10; but it may rise to 0·15.[6] Hence it appears that in this machine there is a very wasteful expenditure of power. This, however, is not a consideration of any importance, provided there is an ample supply of water. The throat being the same, the *useful effect*, according to D'Aubuisson, increases in a greater ratio than the amount of water expended.

Water-wheel, hammer, and anvil.—The hammer is moved by a water-wheel. The entire machinery is represented in fig. 21, which is a section showing the water-wheel, the hammer, and the anvil.

The water-wheels are constructed of wood, and the water falls upon them from a considerable height, say 7 metres (22 ft. 11·59 in.) or upwards, so as to act much more by impact than by weight. They are generally from 2^{m} 50 to 3^{m} 50 (8 ft. 2·43 in. to 11 ft. 5·80 in.) in diameter, inclusive of the buckets. Upon the wooden axis, *a*, is a hollow cylinder of cast-iron, *b*, having four openings to receive the wrought-iron cams, *c c c c*, by which the hammer is put in motion.

The hammer consists of a long stale of wood, one end of which is called the tail, and the other the head. The stale is a cylinder of beech, *d d*, about 0^{m} 35 (1 ft. 1·78 in.) in mean diameter, and 4^{m} 30 (14 ft. 1·29 in.) in length, strengthened with hoops of iron; *e*, a cast-iron collar carrying a horizontal pivot, *f*, on each side, whereby the hammer may move up and down in a vertical plane to the height of from 0^{m} 35 to 0^{m} 47 (1 ft. 1·78 in. to 1 ft. 6·51 in.); at the tail is a piece of beech-wood, *g*, which receives the blows of the cams, and is

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[4] Expériences faites sur les trompes des forges de Vic-Dessos (Ariège). Ann. d. Mines, 8. 1823, p. 595.

[5] Über die Bewegung des Flüssigkeiten. Königl. Akadem. d. Wissensch. für 1848. Berlin. There is a translation of this paper in the Phil. Mag. 4. s. 1. Jan. 1851. p. 1.

[6] D'Aubuisson, Ann. d. Mines, 2. s. 4. 1828, p. 236.

fixed by a half circle of iron, as shown in the engraving; the thickness of this piece of wood determines the height to which the hammer may be raised, and is varied according to circumstances, one piece being used for shingling, and another for drawing out. The head, *h*, is of cast-iron, generally in one piece, and having a hole in it, as shown in section, fig. 21 A, by which it is fitted on the stale; it is firmly secured in its position by oak wedges: it weighs from 600 kil. to 670 kil. (1323 to 1477 lbs.). The hammer rests on a strong framework of oak. On each side is a vertical beam of oak, *i*, supported on a horizontal beam, *k k*, parallel to the long axis of the hammer, and secured by inclined props, *q q*; the two vertical beams of oak are firmly united by transverse beams, *r r*, etc.; *s s*, a rectangular block of oak about 2^{m} 00 (6 ft. 6·74 in.) long, 0^{m} 72 (2 ft. 4·35 in.) deep, and 0^{m} 36 (1 ft. 2·17 in.)

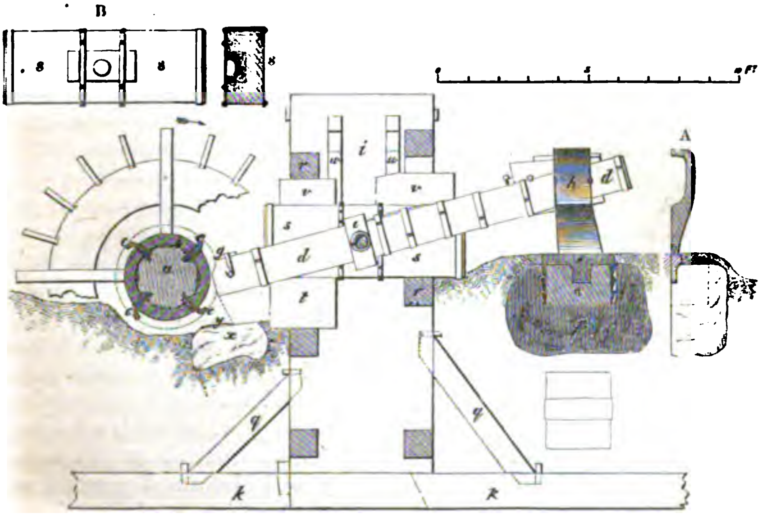

Fig. 21. Water-wheel, Hammer, and Anvil. The framework is shown only on the furthermost side. A. Section of hammer head. B. Complete view of *s s* and section through the middle, showing how the axis of the wheel is received in a cast-iron journal.

thick, firmly hooped with iron, and supported on the left by a large wedge of oak, *t*, and on the right by one of the transverse beams, *r*; there is a similar block, *s s*, on the side of the hammer which does not appear in the engraving; and in these blocks, which are kept solidly in their places by the horizontal wedges, *v v*, and the vertical wedges, *w w*, are inserted wrought or cast-iron journals to carry the pivots of the hammer, *f*; by means of the system of wedges the hammer may be readily and firmly adjusted. Under the tail is a great stone, *x*, and on this during shingling is placed a large iron plate, *y*, upon which the tail strikes and rebounds so as to accelerate the fall of the head of the hammer, which in good work ought to give from 100 to 125 blows per minute.

The anvil, *z*, is made of iron, 0^{m} 70 (2 ft. 3·56 in.) long, 0^{m} 25 (9·84 in.) broad in the middle, and 0^{m} 22 (8·66 in.) broad at each end;

by means of a projecting piece, or tenon, about 0^{m} 13 (5·12 in.) deep, and of the same breadth, it fits into a heavy block of cast-iron a, supported by, and wedged into, a large block of stone, β.

In some forges there are hammers expressly for finishing off the bars, and they are constructed precisely in the manner above described.

Personal establishment in a Catalan forge.—It consists of ten persons,—eight forgemen (*forgeurs*) and two business men, as follows: a foreman (*foyer*) at the head, who constructs the furnace and keeps it in order, superintends the *trompe*, the direction of the twyer, and the charging, and, besides, draws out the iron into bars, produced in alternate operations or *heats*: he has an assistant. A hammerman (*maillé*), who has charge of all that relates to the mechanical treatment of the iron, fits up and watches over the hammer, keeps in order the water-wheel and tools, conducts the shingling of the *massé*, and draws out the iron alternately with the foreman: he has also an assistant. Two smelters (*escolas*),[7] who take charge alternately of the working of the furnace, or in other words, of the treatment of the ore during an entire operation, and they direct and attend to the reheating of the iron in the process of drawing out under the hammer: each has an assistant. Richard considers the *foyer* as overpaid and quite superfluous, and that his duties would be better performed by the smelters, or *escolas*. This division of duties is mischievous, and frequently leads to disputes and recriminations between the *foyer* and *escolas* when the work is not proceeding satisfactorily. There are thus four head men and four subordinates. In addition there are a keeper of the forge and a manager. The keeper has charge of the raw materials and the iron produced, and sees that the furnace is properly supplied with ore and charcoal; his salary is 500 fr. (about 20*l*.) a year. The manager has the forge under his care, and conducts the mercantile part of the business; he is provided with a lodging; his salary ranges from 800 fr. to 1200 fr., *i.e.* from about 32*l*. to 48*l*. per annum.[8] Richard represents them as ill-informed persons, and states that in general the mischievous privilege is accorded to them of selling bread and wine to the forgemen—one of the worst forms of the *truck* system.

The forgemen were paid as follows: each of the four head men received 0^{fr}·45 (3*s*. 9*d*.) on the quintal of 40 kil. of merchant iron produced; the assistants of the foreman and hammerman received 0^{fr} 225 per quintal, and in addition were supplied with food by the master, with the exception of bread; the assistants of the smelters received 6 fr. (5*s*.) weekly, and were kept by their masters.

Mode of conducting the process.—A charge of 12 quintals (487 kil. = 1078·8 lbs.) of ore is weighed out, and crushed under the forge hammer; it is thus reduced to powder more or less coarse, and into pieces, of which the largest are from 0^{m} 05 to 0^{m} 06 (1·97 in. to 2·36 in.) in diameter; it is then divided by sifting into lumps (*mine*), and very

[7] They derived their name from *escoula*, the patois for *écouler*, because they pierce the tap-hole for the *écoulement* or drawing-off of the slags. François.

[8] All the preceding details are from François.

coarse powder (*greillade*), which contains a much larger proportion of earthy matter than the *mine*. The bottom of the sieve employed is formed of concentric iron wires, rather less than 0m 01 (0·39 in.) apart, and supported by a few iron wires placed radially. The *greillade* is strongly tempered with water, and is piled in a heap on the right of the furnace at a convenient distance. With good brown hæmatite the *greillade* may amount to about half of the whole ore.[9]

The furnace is supposed to be heated from a previous charge and to be in proper working order, a mass of incandescent charcoal and residua from the last lump of iron remaining upon the bottom. The blocks of iron forming No. 2 side are quite red hot as high up as the twyer; and so are those of the opposite side, No. 4, about half-way up; Nos. 1 and 3 sides, as well as the bottom, are also red hot. After having "cleaned the fire" (*nettoyé le feu*), the charcoal withdrawn from the furnace in the last operation and the residua which may also have been taken out of it are put back into the furnace. Fresh charcoal is then immediately thrown on the top and packed[1] (*tassé*) by the furnace-man, who for this purpose uses a spade, striking sometimes with the flat side and sometimes with the edge, so as to break the largest pieces of charcoal, and press them well together. When the charcoal nearly reaches the lower end of the twyer, the hearth is divided vertically into two parts by a long broad shovel or plate of iron parallel to, and distant from, No. 2 side, about $\frac{2}{3}$ of the way between No. 2 and No. 4 sides. On the left of this plate, *i.e.* on No. 2 side, charcoal is added and packed; a few handfuls of charcoal are also thrown in on the right of the plate, when the whole between No. 4 side and the plate is pressed strongly down with a flat ended tool. Upon the very solid bed of charcoal thus prepared a box of ore is emptied, the ore being allowed to slide down over the sloping side No. 4 and then packed. Charcoal is again piled and packed on the left of the iron plate, and then a second box of ore on the right of the plate. Lastly, a third box of ore is added in the same manner as the second, after which the furnace-man adroitly slides out the shovel or plate of iron dividing the hearth; and in doing this he inclines it nearly parallel to No. 4 side, so as to throw the wall of ore a little back on the sloping bank supporting that side, upon which it distributes itself according to its natural talus. The ore now forms a mass having two taluses, one on the left and the other on the right; and the crest between the two, which rises on No. 3 side nearly 0m 3 (11·81 in.) above, and a little on the left of the edge of No. 4, abuts about midway on the sloping top of No. 1. The talus on the left is completely covered with moistened charcoal breeze, which is well beaten down. Over this breeze small charcoal is piled up as high as the crest, and again on the top of this moistened breeze is placed: the whole is well beaten down with a spade, so as to make this wall perfectly solid, after which a good blast is turned on. All this is the affair of a few minutes.

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[9] François, p. 271.

[1] Packed is the best word I can find for the French *tassé*, in the sense here used.

Hardly has the blast been turned on when an infinitude of jets of blue flame from 0^m 06 to 0^m 10 (2·36 in. to 3·94 in.) escape from every part of the wall of ore not covered with charcoal on the right. If similar jets appear on the talus on the left, small moistened charcoal is immediately thrown over them and beaten firmly down; but if, on the contrary, they are not produced on the right, the hearth is either cold or ill constructed, or the charging has been badly done. After the lapse of a few minutes, during which the tap-hole on No. 1 side is stopped with clay, the blast is diminished, so that the gauge marks 6° (= 0^m 027 = 1·07 in.).

Richard has given a most detailed description, or *procès-verbal*, of the operation of working off a charge, or *heat;* and from this, which fills 12 quarto pages, I shall subjoin the chief points of interest. It is necessary to premise that the iron which is reduced in this process is agglutinated into a large lump below the twyer; this lump, which is termed *loupe* or *massé*, is hammered or *shingled* under a heavy hammer or *helve*, and divided into three pieces, one from the central portion, the *massoque*, and the other two from the ends, the *massoquettes*. These several pieces are drawn out under the hammer into bars, and during this operation it is necessary to reheat them several times. The reheating is effected in the same furnace as serves for the reduction of the ore, and takes place on No. 2 side above the twyer. The inclined top of No. 1 side, or the *banquette*, affords facilities for introducing and withdrawing the *massoque* and *massoquettes*. Further details concerning this part of the manipulation will be given in the sequel. Two men are required at one furnace—a headman, or *escola*, who takes the management and performs all the work requiring skill, and an assistant, or *valet*, who acts as a labourer in supplying charcoal, ore, etc.

The furnace having been charged in the manner above described, the trees are opened to the full extent, and the gauge marks 18° (0^m 0812 = 3·19 in. of mercury). Charcoal is thrown into the angle between Nos. 2 and 3 sides, so as to form an inclined plane descending from the crest of the wall of ore to about 0^m 25 (9·84 in.) below. The contents of the furnace are kept up at a constant level by the addition of charcoal and ore in the state of *greillade* at repeated intervals during what is termed the first stage of the process, which in Richard's *procès-verbal* is stated to last 1 h. 13 m. After every such addition water is thrown on the top. In about 8 m. the gauge is made to mark 8° (0^m 0361 = 1·42 in.), and is maintained at this degree during the whole of the first stage.

The second stage now begins, and the gauge is raised to 10° (0^m 0451 = 1·78 in.). The furnace is kept supplied with charcoal and *greillade*, water being thrown on from time to time to prevent unnecessary consumption of fuel. In 1^h 46^m a small charge of scoriæ coarsely broken up from the last *massé* is added instead of *greillade*. In 1^h 59^m the taphole is opened for the first time, and the cinder (*scories lourdes*) which runs out is sprinkled over with water, after which it is put back into the furnace and covered with charcoal.

In 2^h 22^m the gauge is suddenly raised to 14° (0^m 0632 = 2·48 in.),

and the third stage commences. A portion of the ore in lumps, and not *greillade*, is now introduced for the first time; this is done by inserting a bar between the blocks of cast-iron forming No. 4 side and the superincumbent ore, of which more or less is made to drop down into the hearth. This operation is termed "*donner la mine.*" Charcoal, *greillade*, and water continue to be added at intervals. In 2^h 56^m, the cinder having been tapped off a few minutes previously and the tap-hole *left open*, the flame from the hearth whitens, resembling the bright light produced by the burning of iron in oxygen, when the tap-hole is instantly closed.

In 3^h 4^m the gauge is raised to 16° (0^m 0722 = 2·84 in.), and the fourth stage begins. The same series of operations is repeated; such of the cinder as is found *too heavy* is put back into the furnace. In 3^h 25^m the reheating process connected with the last formed *massé* now ends. In 3^h 33^m Richard states that the point of an iron bar, used in the manipulations, comes out of the furnace encrusted with a coat of iron, varying from 0^m 004 to 0^m 008 (0·16 in. to 0·31 in.) in thickness; this coating after cooling in water and scraping with a knife presents a very brilliant white surface. At about this period Richard has constantly observed that a yellow powder begins to cover the charcoal, for which he has never been able to account. "It occurs constantly, and always towards the fourth hour from the beginning of the process, whatever be the quality of the charcoal or ore employed. The whole surface of the incandescent charcoal, situated at the upper part, is coated with a kind of ash of a sulphur-yellow colour, perfectly distinct and sometimes brilliant (*éclatant*)."[2] Richard allowed pieces of charcoal coated with this yellow powder to cool out of contact with atmospheric air, and found it persistent. The workmen attribute it to sulphur, which is of course absurd. I do not know what it could be.

In 3^h 50^m the gauge is raised to 18° (0^m 0812 = 3·19 in.), and the fifth stage begins. Charcoal and ore in lumps are supplied at intervals. The flame has become somewhat less blue, the charcoal is almost everywhere in ignition at the surface of the hearth, and the whole of the wall of ore has disappeared under the charcoal. In 3^h 59^m cinder is tapped off, and "flame issues from the taphole with a noise resembling distant thunder." In 4^h 10^m the level of the mass of charcoal on the hearth is about as high above the furnace as the latter is deep. In 4^h 19^m it is evident that the *massé* now occupies a considerable space under the charcoal. Charcoal is copiously supplied, the cinder, which has become very poor in iron (*très maigre*), is tapped off at intervals, and ore introduced from side No. 4 in the manner before described. In 5^h 29^m the furnace-man breaks off the angles of the *massé* on No. 1 side, and pushes towards the centre of the hearth the various pieces of iron which may remain scattered through the charcoal, and endeavours to unite them to the *massé*. This operation is termed *la baléjade*. In 5^h 38^m the furnace-man again breaks off the projecting edges and

[2] Op. cit. p. 261.

asperities of the *massé*, and may now be said to be giving "the last touch to his work;" he detaches any pieces of iron which may remain adherent to the sides of the hearth, and pushes them towards the middle of the *massé*, so as to solder them to it. In $5^h\ 43^m$ the flame suddenly whitens and becomes very bright, which, according to the furnace-man, is a sign that the iron is *consuming itself*, or burning to waste (*se mange*). In $6^h\ 3^m$ the blast is stopped, and the blast-pipe drawn backwards. The charcoal covering the *massé* is then thrown on the bank on No. 4 side, and extinguished with water. A very strong bar of wrought iron (0^m 07 to 0^m 08 = 2·76 in. to 3·15 in. in diameter) is introduced through the tap-hole under the *massé*, and the long iron of this lever is subjected to a series of powerful jerks downwards by one or two men standing and jumping upon it. After having been thus completely detached, the *massé* or lump is taken out of the furnace over No. 1 side, in the manner shown in fig. 14.

The operation from which Richard took his description lasted longer than it ought to have done, owing, it was alleged, to the defective state of the twyer; and consequently more than the proper amount of charcoal was consumed.

The entire process, which I shall designate indiscriminately by the terms *fire* or *heat*, lasted $6^h\ 3^m$. According to Richard, during this period 106^k 62 (235·1 lbs.) of water were evaporated, of which 51^k 5 (113·56 lbs.) were thrown upon the fire, the rest having been derived from the charcoal; the total weight of air supplied by the trompe was 2800^k 03 (6174 lbs.), the average weight of air per minute 7^k 71 (17 lbs.), the total carbon converted into gas was 461^k 32 (1017·2 lbs.), the average amount of carbon thus consumed per minute was 1^k 27 (2·8 lbs.), the quantity of charcoal consumed was by *weight* 544^k 7 (1201 lbs.), or by *volume* $2^{c.m.}$ 412 (85·185 c. ft.), the bars drawn out from the *massé* weighed 3^{qx} 79, or 151^k 6 (334·27 lbs.), and the quantity of ore employed was 12^{qx}, or about 487^k (1073·8 lbs.).

It must not be supposed that every furnace-man conducts the process in exact accordance with the foregoing description; for the practice of different men, though in essential particulars the same, differs in points of minor detail.

According to François, in the forges of Ariége 100 kil. of merchant iron are generally obtained from 312 kil. of ore, with a consumption of 340 kil. of charcoal, and the average duration of a *heat* is 6 hours. Richard estimates that in good work 100 parts by weight of ore should yield 31 of bar-iron and 41 of slags, containing about 30 per cent. of metallic iron.[3] Yields obtained by Richard from the forge du Rossecq were ore 100, bar-iron 31·2, and slags 50·2—ore 100, bar-iron 31, and slags 51·8.[4] Care was taken to collect the slags as free from dirt as possible, and to dry them before weighing. From the 40 forges in activity in Ariége, each making annually on the average 1000 fires or heats, Richard calculated that "2,400,000 kil. (about 2400 tons, of 2240 lbs. to the ton) of iron were lost every year in the

[3] Op. cit. p. 154. [4] Op. cit. p. 155.

slags, which during many centuries past had been spread over the roads or thrown into water courses."

A good *massé* is a more or less spheroidal lump, smooth on the exterior, and free from irregular projecting pieces; its upper surface presents a depression corresponding to the nozzle of the twyer; it should be red-white hot when taken out of the fire.

The characters of the slags afford important indications of the working condition of the furnace. They are generally bluish-black. They should flow easily, and after quenching with water should be light and friable. They should not run thick, nor throw out sparks on coming in contact with the air, which is a sign that they contain shots of metallic iron. However, the slags which are at first tapped off frequently contain much iron, when, as we have seen, they are put back into the furnace.

When the furnace is in good working order the *eye* of the twyer, *i.e.* the point of light seen through the broad end, should be bright white.

François minutely describes many other indications concerning the condition of the furnace, which can only be properly learned by practice.

Theory of the process.—Richard and François have investigated the progressive changes which occur in the Catalan furnace by carefully examining the contents at different stages of the process. In order to make these observations furnaces working under the same conditions were extinguished at successive intervals from the beginning to the end of a "heat." François has published numerous and very minute details on this subject, and has described the microscopic appearances of the ore undergoing reduction. In the following pages I shall avail myself largely of the labours of this author, and translate freely from his work.

In reading the foregoing description of the process, the metallurgist will be struck with the peculiar manner in which the wall of ore in *lumps* is arranged on No. 4 side, and is gradually pushed down into the furnace, while pounded ore (*greillade*) is introduced from time to time in alternation with charcoal. Now, by this arrangement the gaseous products of combustion are compelled as far as practicable to traverse the wall of ore, which, consisting of detached lumps, offers no serious obstacle to their passage. But carbonic oxide is a chief constituent of these gaseous products, and will reduce the ore in a greater or less degree before the latter falls into the body of the hearth. The ore being brown hæmatite, or hydrated sesquioxide of iron, loses its water of combination at a comparatively low temperature, and becomes porous, fissured, and consequently pervious to gas. It is on this account that brown hæmatite not too compact is so much in request for the direct method of extracting iron.[5] Reduction will take place gradually in the wall of ore from the bottom towards the upper and outer parts, and between these limits there will obviously be every

[5] François, p. 228.

degree from metallic iron to unchanged ore. This method of effecting the reduction of the ore is very ingenious, and well worthy of attention.

As the ore descends into the hearth it is exposed to a gradually increasing temperature, which at length becomes sufficient to cause the silica to combine with the associated earthy bases and a considerable quantity of protoxide of iron with the formation of a very liquid slag or "cinder." The particles of reduced iron being exposed to a welding heat unite together into a somewhat spongy lump, or *massé*, which retains a considerable amount of intermingled slag. The ore introduced in the state of *greillade* is reduced also with the formation of slag, and the iron separated contributes to the growth of the *massé*. The *massé* is subjected to repeated blows under a heavy hammer, whereby the slag is more or less completely extruded, and the iron consolidated into a compact mass, or "bloom."

The *greillade* being in the state of coarse powder presents a very large surface to the reducing action of the ascending current of carbonic oxide and the incandescent charcoal with which it comes in contact; and it must, therefore, be speedily reduced, when the resulting particles of metallic iron will sink and collect into a cake at the bottom before any iron has been detached from No. 4 side. This cake is termed "*principe du massé*," and is quaintly compared to a fœtus by Richard: it forms a thin covering over the hearth-bottom, and catches the pieces of iron subsequently reduced. It is important that the *principe* should be in the centre of the furnace, neither too high nor too low, and a little towards No. 3 side. It may happen that the *principe* may be badly placed near one of the sides of the furnace, when it must be detached in order to induce the formation of a second in a better position.[6] Sometimes two or even more *principes* are formed, in which case a sound and homogeneous *massé* cannot be obtained.

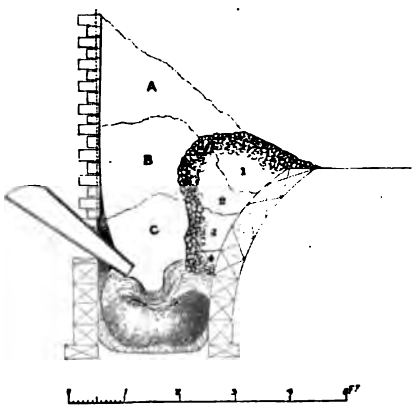

Fig. 22.
Vertical section through the axis of the twyer of a furnace during the *balejade* part of the process.

François has divided the furnace into several distinct regions, corresponding to the reactions which predominate in each. This is done simply with a view of fixing upon the mind the gradual and successive changes which the ore undergoes in the process of reduction; and, although the limits which he assigns to these several regions in the accompanying diagram, fig. 22, are such as actually exist in a furnace in good working

[6] François, p. 45.

order, and with everything as it should be during the *baléjade* part of the process, yet, so far from these limits being constant, François states that they are subject to the widest, most irregular, and most whimsical variation, according to the condition of the furnace, the nature of the ore, the quality of the charcoal, and the kind of blast.[7] With respect to the ore in lumps, in No. 1 calcination predominates; in No. 2 reduction and the appearance of pellicles of metallic iron are chiefly observed; No. 3 is characterized by more active reduction, incipient carburization, and the slagging and liquation of the earthy matters; in No. 4 reduction, liquation of the earthy matters in the form of slag, and carburization take place simultaneously with great activity.[8] With respect to the ore in the state of *greillade*, in A, at about 0^{m} 20 (8 in.) below the surface, calcination and reduction predominate; in B, which descends to 0^{m} 50 (about 1 ft. 8 in.) below the surface, the characteristic phenomena are reduction and the formation of slag (*scorification*); in C, which includes the bath of slag, reduction and liquation are developed.[9]

At the upper part of region No. 1 the ore is in detached pieces, having the form but neither the colour nor the texture of the raw ore. The colour has changed from ochreish red to bluish black, with a slightly metallic lustre; and the texture has become more compact and closer in grain. Over the entire surface of each piece of ore fissures and cracks are visible, which extend to a considerable depth; and every fragment is magnetic. The presence of magnetic oxide of iron is indicated by a compact texture, close grain, and bluish black colour, especially upon the external surface of the pieces and the sides of the cracks, or those parts most exposed to reducing action; and the layer formed by this oxide increases with the depth of region No. 1. If the ore is much fissured (*chargé de fissures*), the whole of the sesquioxide of iron which it contains is converted into magnetic oxide before any iron is reduced. If, on the contrary, it continues close in structure and free from fissures, the same piece may present metallic iron on the surface, then a layer of the oxide of iron scale and magnetic oxide in the centre; but, according to François, this hardly occurs except in specimens of compact sesquioxide of iron.

François has given the following analysis of a mixture of several lumps of different sizes taken from the middle and bottom of region No. 1. Specific gravity = 4·545, that of the raw ore on the average = 3·650.

Sesquioxide of iron	49·21
Magnetic oxide of iron	26·95
Brown oxide of manganese (Mn^3O^4)	4·12
Lime and magnesia	6·00
Clay and quartz	12·55
Loss by calcination (O and CO^2)	1·05
	99·88

There was scarcely more combined silica present than in the raw ore. The carbonates had not yet been completely deprived of car-

[7] Op. cit. p. 225. [8] Op. cit. p. 226. [9] Op. cit. p. 246.

bonic acid, nor the peroxide of manganese wholly converted into brown oxide.

Below the line of separation between regions Nos. 1 and 2, the lumps of ore, according to François, are superficially coated with a pellicle or skin of iron, which is rendered manifest on fracture, and which on lumps from the lower part of region No. 2 measures from 0^{m} 001 to 0^{m} 003 (from 0·04 in. to 0·12 in.) in thickness. Under the microscope this pellicle is seen to consist of a confused aggregation of particles of iron and imperfectly formed slag. The body of the lump within the pellicle is bluish black, slightly vitreous, has a fatty lustre and wrinkled texture.[1] On breaking the lumps across, traces of the principal fissures and the metallic parts which lined their sides are still visible in the body forming the interior.[2]

François has given the following analyses of ore from this region. Specific gravity of No. 1 = 4·695, and of No. 2 = 5·250.

	1.	2.
Metallic iron	1·04	4·15
Sesquioxide of iron	22·91	11·23
Protoxide of iron	59·21	60·83
Oxide of manganese	4·02	5·50
Lime and magnesia	5·20	9·93
Clay	4·55	
Combined silica	2·10	8·47
	99·03	100·11

No. 1 from the middle, and No. 2 from the lower part of region No. 2. The increase in the proportion of combined silica will be remarked, especially in No. 2, in which the whole of the silica existed in combination.

François collected the gases from region No. 2 and found them to contain carbonic acid, though in less proportion than in region No. 1. He states that "the flame was highly charged with particles of charcoal." So great is the amount of charcoal which may thus be driven off in fine powder, that it covers the roofs of the forges more than half a foot deep, and hangs in odd-shaped stalactites to the wall of the furnace above the twyer side.[3]

In region No. 3 more active reduction occurs. The lumps of ore become soldered together at their angles, without however sensibly changing in form. The metallic pellicle "is developed and becomes a true integument," of which the thickness amounts even to 0^{m} 002 (0·08 in.), or more. The interior or kernel of a lump is a pasty mass, completely scorified and intumesced, especially in the vicinity of the metallic integument. In the lower part of this region, where the temperature is stated to be about 1000° C. (deep orange), all the phenomena above described advance with rapidity, and the lumps, with their integuments, become rounded. When cut in two at this stage there is constantly observed a scoriaceous, somewhat metallic

[1] *À texture rugueuse*, literally rugose or wrinkled texture.

[2] *Noyées dans la pâte intérieure. Pâte* is here used in the sense in which the potter employs the word *body*.

[3] Richard, p. 160.

mass, included within a malleable envelope, of a dull grey colour, and having frequently the aspect and grain of *white cast-iron*, *a a a*, fig. 23. François describes this as steely iron (*fer aciéreux*), contaminated with scoriaceous, often crystalline matters. The external surface is spotted with drops of dirty greenish yellow slag, which exude through pores in the envelope, visible under a lens and often with the naked eye, *c c c*, fig. 23. The internal surface of the integument is studded with branching stalactite-like projections of iron, *a a a*, which show how it grows and is developed by means of iron derived from the mass within. This mass, as reduction proceeds, yields iron to the branching projections, of which the extremities are immersed in very liquid intumesced, chocolate-coloured slag, charged with microscopic shots of metallic iron. The internal nucleus has a metallic black colour (*d'un noir métallique*), is vitreous and completely scorified (*entièrement scorifié*). Its substance is charged with shots of metal, and filled with microscopic spherical cavities, which increase in number and size towards the exterior. These cavities, as François observes, prove the penetration and disengagement of gaseous products.

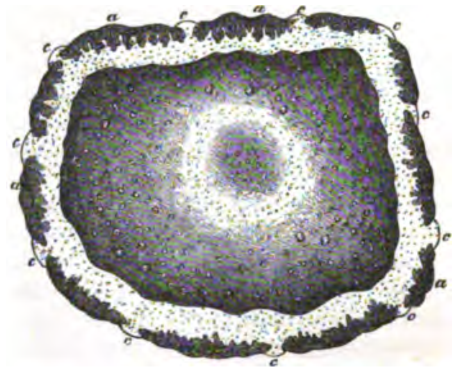

Fig. 23. Section of a lump of ore during the process of reduction

François has given the following analysis of the internal portion or kernel of a lump of ore in this stage. It is described as semi-fused, intumesced, pasty, metallic black in colour, and vitreous in texture. Average specific gravity 4·699.

Silica	27·50
Protoxide of iron	41·20
Protoxide of manganese	11·65
Lime	9·60
Magnesia and alumina	2·50
Shots of metal	7·55
	100·00

The metallic integument is described by François as steely iron, mixed with about 30% of slag. Its specific gravity ranged from 5·540 to 5·941. The slag thus intermixed with iron is most frequently in crystals visible under a lens, and consists of tribasic silicate ($3RO,SiO^3$). The slag within the metallic envelope has similar characters, but it is always charged with branched microscopic particles of iron; and in the vicinity of the internal nucleus it becomes richer in iron.

The gas collected in region No. 3 burned with the blue flame of carbonic oxide, and contained only a very small quantity of carbonic acid and a little hydrogen.

In region No. 4, the temperature of which is estimated at from 1200° to 1300° C. (orange-white), the lumps become flattened, and the slag with which the iron of the integument is contaminated separates in great measure by liquation, while the scattered particles of iron, coming in contact at a welding heat, unite and form a spongy mass. According to François, reduction, liquation, and the development of the integument take place better in proportion to the degree in which the ore has been fissured and split in regions Nos. 1 and 2. The formation of the integument, on the contrary, languishes when the ore is too coherent, or when there is a deficiency in the necessary ingredients, especially silica, to produce a tribasic slag. In the first case, the development of the integument takes place uniformly; it is close in texture; its specific gravity often amounts to 7·063; and it is less charged with slag, of which the liquation is effected with rapidity, especially in the presence of a base, like protoxide of manganese, which forms very fusible slags irreducible at the temperature of the furnace. In the second case, the integument is unequally developed, reduction is retarded, and, liquation being impossible, the integument is charged with pasty slag, and has consequently a specific gravity ranging from 4·210 to 5·567. It then frequently happens that lumps of ore descend into region No. 4 with only a feeble pellicle, when they melt and run into the bath of slag at the bottom in the state of highly basic silicates, of which the reduction is mostly imperfect. This evil may be due to the absence of a proper proportion of silica, or to the presence of too much carbonate of lime. At the bottom of region No. 4 the integuments are in great measure united strongly together.

François remarks that the slag forming the bath at the bottom of the furnace always contains more base than the tribasic silicate, and that there is always association and proximity of tribasic silicate with metallic iron. When the furnace is in good working order the slag on the whole approximates very sensibly to tribasic silicate.

François has given the following analyses of the metallic integuments from region No. 4.

	1.	2.	3.
Specific gravity	6·140	6·215	7·063
Metallic iron	76·095	78·675	83·100
Slag	·23·100	20·400	15·620
Carbon	0·605	1·055	1·250

No. 1, from a furnace yielding ordinary soft iron (*fer doux ordinaire*). Nos. 2 and 3, at the lower part from a furnace yielding strong or steely iron (*fer fort*); carburization had taken place to a considerable extent in these pieces of iron, and this condition occurs when there is no longer any internal nucleus to reduce, and, consequently, no highly basic silicate to yield, by the reduction of a portion of its protoxide of iron, oxygen to decarburize the contiguous iron.

The gas collected in this region burned with the blue flame of carbonic oxide, and contained only traces of carbonic acid.

In the reduction of the *greillade* the same succession of phenomena occur as in the lumps of ore which descend gradually into the furnace

on No. 4 side; but the action must obviously be more rapid in the *greillade*, consisting as it does of small particles of ore, than in the comparatively large lumps of ore on No. 4 side. According to François, in region A, fig. 22, at about 0^m 20 (7·87 in.) below the surface of the fire, calcination and reduction predominate; region B, which descends to 0^m 50 (1 ft. 7·69 in.) below the surface, is characterized by the phenomena of reduction and scorification; and, lastly, in region C, which contains the bath of slag, reduction and liquation are developed.[4]

François states that in region B all the pieces of charcoal imbedded (*empâtés*) in the *greillade*, which is now in a pasty state from the formation of silicates, become very exactly coated with a metallic pellicle of iron. He further remarks, "that a similar coating is not only observed upon charcoal, but is produced upon the surface of every solid infusible body which may be plunged into the *greillade* on fusion. It is not merely the effect of contact between the charcoal and easily reducible basic silicates, but is due to the fact that the air blown in and converted into reducing gas, by preference passes between the metalliferous paste and the immersed body, as it there meets with the least resistance in rising through the fire. The marked tendency of a highly basic silicate to pass into the state of tribasic silicate determines in the case of pieces of charcoal a more active reduction, because these pieces not only act like immersed bodies, but burn under the blast, causing in the vicinity a high temperature and the formation of reducing gases."[5]

François asserts that the external face of the metallic pellicles is always coated with chocolate-brown crystals of tribasic silicate; and that the slag which liquates has invariably this formula, provided the operation is not badly conducted and not too hurried.

According to the same authority, though the reduction and fusion of the *greillade* take place rapidly, yet the reduction is far from perfect, as the slags of the first tappings always contain much more iron than the tribasic silicate, and are often put back into the furnace. A decarburizing action would be produced by such highly basic slag upon any iron which may have taken up carbon, the latter reducing an equivalent proportion of protoxide of iron in the slag, and being evolved in the state of carbonic oxide. With reference to the incompleteness of the reduction of the *greillade*, Richard goes so far as to write—"Examinations of extinguished furnaces (or, as he quaintly says, *autopsies*—a term applied to examinations of dead bodies) and some laboratory experiments seem to demonstrate to me that it reaches the lowest part of its course without the oxide of iron which enters into its composition being *ever* reduced to the metallic state."[6] He considers that almost the sole object of the *greillade* is to protect the pieces of iron already reduced and carburized from oxidation and decarburization when the smelter brings these pieces successively near the end of the twyer in order to weld them finally together. In the vicinity of the end of the

[4] Op. cit. p. 247.

[5] Op. cit. p. 248. It has been previously shown in this work that there is no more highly basic silicate of iron than tribasic.

[6] Op. cit. p. 283.

twyer the atmosphere of the furnace may be highly oxidizing; and a spiteful smelter sometimes avails himself of this fact to burn away the iron from the last *massé* during the process of re-heating. He thus reduces the yield of his predecessor, and may increase the weight of his own *massé*. The *greillade*, it will be remembered, contains much more earthy matter than the *ore in lumps*, and, as silica is generally the chief constituent of this matter, a proportionately large amount of slag must be produced.

That portions of the iron reduced may take up a considerable quantity of carbon is proved by analyses which have been previously introduced, and by others which will follow; and it, therefore, seems probable that partial carburization and subsequent decarburization by a highly basic slag, consisting essentially of silicate of protoxide of iron, may be pretty constant phenomena in the Catalan furnace.

François has given the following analyses of iron from the upper surface of the *massé*. The metal was in branched fragments (*fer ramuliforme*), but little malleable, and contaminated with slag.

	1.	2.
Specific gravity	7·423	7·042
Metallic iron	94·870	93·216
Manganese	0·521	0·025
Silicon	0·037	0.020
Carbon	traces	0·420
Slag	4·562	6·319
	99·990	100·000

No. 1, from a furnace yielding soft iron (*allure en fer doux*), with manganesiferous ore. No. 2, from a furnace working in the usual way, with an ore of sesquioxide of iron.

Richard and François have given the following analyses of the slags produced in the Catalan process.

	1.	2.
Silica	33·542	33·00
Protoxide of iron	41·771	39·87
Protoxide of manganese	12·310	13·00
Lime	8·541	7·20
Magnesia	1·321	2·35
Alumina	1·905	3·65
Shots of iron	..	1·20
Loss	0·610	..
	100·000	100·27

No. 1. By Richard.[7] Mean composition of all the slags accompanying the formation of a *massé* from 12 quintals (487 kil.) of ore and *greillade*, and which yielded 150 kil. of iron in bars. No. 2. By François.[8] Average of eight analyses of slags, both amorphous and crystallized. The specific gravity of a crystallized slag entirely free from metallic iron was 2·056.

In these slags the oxygen of the silica is about equal to that of the bases, so that their formula is $3RO,SiO^3$, which is that of peridot or

[7] Op. cit. p. 151. [8] Op. cit. p 234.

olivine. Dufrénoy examined some of the crystallized slags with which François supplied him, and ascertained that they had the form of that mineral. It will be seen in the sequel that such crystals are frequently produced in the manufacture of iron. The colour of the slags of the Catalan furnace, according to François, is chocolate brown, often of an olive tint, and occasionally amber-yellow. When free from metallic iron, the tribasic silicate is not magnetic.

Conditions affecting the quality of the iron produced in the Catalan furnace.—French writers specify two distinct qualities of iron—one, "*fer doux*," or soft iron, and the other, "*fer fort*," or steely iron (*natural steel*). This difference essentially depends upon the amount of carbon in the iron, the soft iron containing either none or only a small proportion of this element, and the steely iron containing it in very sensible proportion. Between the two extremes of quality there may be every gradation. We shall now proceed to consider the special conditions which favour the formation of these two qualities of iron. It will only be necessary to examine in detail the conditions which determine the production of steely iron or steel; for the converse of these will be the conditions favourable to the production of soft iron.

The conditions which tend to produce steely iron or steel (*fer fort*) are as follow:[9]—1. Less *greillade* and more charcoal is employed. 2. The ore (*mine*) on No. 4 side is oftener pushed towards the twyer, or, in other words, gradually and slowly. 3. The tappings of the slag are more numerous. 4. Above everything, more time is allowed for the formation of the *massé*. 5. It is maintained by some persons and denied by others, that the twyer should be less inclined and No. 4 side thrown more back (*plus renversé*). 6. Less blast should be given towards the end of the process than in the case of soft iron. 7. Dense charcoal, especially that of oak, is more favourable to the formation of steel than light. 8. The presence of a considerable amount of manganese in the ore. After all, much may depend on the manipulation of the furnace-man, for with the same materials one man will produce much steel, while another will only produce little or none at all.

It is affirmed that steely iron generally, though by no means invariably, occurs at the upper part of the *massé*, towards its circumference, and particularly in that part which corresponds to the tap-hole.

I shall now proceed to examine the rationale of these conditions seriatim. The two objects to be attained are the promotion of carburization and the prevention of subsequent decarburization. 1. Carburization of the iron will obviously be promoted. 2. If this part of the manipulation is practised more frequently, the ore in lumps must be detached in smaller portions, and, therefore, exposed to more extensive contact with incandescent charcoal, a condition favourable to carburization. 3. Contact of the *massé* in process of formation with highly basic slag of protoxide of iron is less prolonged, and less slag is allowed to accumulate on the bottom of the furnace at a time; and we have seen that such slag exerts a decarburizing action on iron. More-

[9] Richard, p. 274 et seq. François. p. 267 et seq.

over, if the statement of Richard be correct, that the amount of this slag is in great measure proportionate to the amount of *greillade*, less of this slag is produced, since less *greillade* is employed. The fact above mentioned, that when steely iron is formed it will generally be found at the upper part of the *massé*, may, possibly, be due, at least in a certain degree, to the circumstance that the lower part of the *massé* must be more constantly surrounded with slag and less continuously in contact with incandescent charcoal than the upper part. 4. This implies longer contact of the reduced iron with incandescent charcoal before it reaches the *massé*. François lays stress on the greater length of time during which the ore on No. 4 side remains exposed to the action of *cementation*, and to the more complete reduction of the ore in the interior of the lumps, whereby the formation of very highly basic and decarburizing slag is prevented. 5. The more directly the blast impinges upon the *massé*, the more is its surface exposed to oxidation, or, what is equivalent, to decarburization. 6. Less oxygen will pass through the furnace in a given time, and what does pass will have less velocity; and, though the temperature may be thereby somewhat lowered, yet the reduced iron in its descent will be kept longer in contact with incandescent charcoal: there will also be less free oxygen in the gaseous current passing through the furnace, and the iron will be less exposed to decarburization. 7. This will tend to secure the same condition as that last mentioned. 8. François explains the action of oxide of manganese by its readily forming a very liquid, irreducible slag, not more basic than tribasic silicate, and, consequently, a slag which is not decarburizing, and serves to protect the iron which may have become carburized. As it is not sensibly reduced in the Catalan furnace, it passes into the slag, forming a substitute for oxide of iron, whereby the yield of iron is increased. François states that he has satisfied himself that steel, either strong or mild, did not sensibly lose carbon by being kept immersed at a red-white heat during 5 hours in manganesiferous slag (*dans un bain manganésé*).[1]

If the *greillade* is too siliceous, it may produce slags which *gob* the fire (*empâtent le feu*), the furnace works cold and irregularly, and the result is a tender and unsound iron. If, on the contrary, it is too calcareous, it produces yellowish-green, generally pasty slags, the furnace works sluggishly (*l'allure languit*), and the result is a tender, unsound, and red-short iron.[2]

When the furnace is *on soft* iron, with a fusible ore and light charcoal, the twyer is more inclined than with a refractory ore and strong charcoal; and when *on steely* iron, the twyer must neither be too horizontal nor too inclined, in order that, on the one hand, the blast may not act too rapidly upon the ore, and, on the other, that it may not oxidize the *massé*.[3]

The condition of the blast as to moisture influences the quality of the iron produced. Although the blast from the trompe must always be saturated, or nearly so, with moisture, yet the amount of water mechanically carried over with it may vary considerably, so that it may be *comparatively* dry or wet. With a *dry* blast the furnace works

[1] Op. cit. p. 272; also p. 279. [2] François, p. 271. [3] Ibid. p. 285.

hotter, more equably, and, *cæteris paribus*, a softer and more homogeneous iron is obtained than with a *wet* blast, when the furnace heats badly on account of the extra quantity of water thrown into it, and the result is an unsound, badly welded, and irregularly steely iron. Hence, under the ordinary conditions of working in the Catalan furnace, the blast of the trompe favours the production of steely iron, and that of blowing cylinders the production of soft iron.[4]

François has recorded some interesting results which he obtained with a mixture of brown hæmatite and refuse manganese ores.[5] Of these he has given the following analyses.

	1.	2.
Loss by calcination	17·60	18·30
Oxide of iron	9·60	10·12
Oxide of manganese (Mn^3O^4)	62·60	58·00
Lime	3·40	2·25
Magnesia	traces	traces
Clay	7·00	11·30
	100·20	99·97

The twyer was less inclined than usual, and *greillade* was employed in moderate quantity. The mixture of ores consisted of 425 kil. (937 lbs.) of good brown hæmatite, containing 44 % of iron and 33 kil. (72·7 lbs.) of refuse manganese ore. The yields obtained were, iron in blooms (*massoques*) 170 kil. (374·8 lbs.), and iron in bars 163 kil. (354·4 lbs.), with a consumption of 301 kil. (663·7 lbs.) of charcoal per cent. of bar-iron (*fer forgé*). The lóss in drawing out into bars was only 9 instead of 13·50 per cent. The iron obtained was perfectly welded and clean (*essuyé*) on leaving the furnace; it was soft, very homogeneous, and filed and hammered well; it was much sought after for making steel by the cementation process, and produced steels easily worked in the fire, malleable, and remarkably weldable. He attributes this to the presence of manganese in the iron, and the formation of slags, which protected the steel after its formation in the furnace. He gives the following analyses of the iron and slags.

Iron.	1.	2.
Metallic iron	99·63	99·55
Manganese	0·12	0·20
Silicon	traces	traces
Slag	0·10	0·15
	99·85	99·90

Slags.	1.	2.
Silica	33·00	29·00
Protoxide of iron	28·10	29·00
Protoxide of manganese	18·70	9·00
Lime	..	8·90
Alumina } Magnesia }	20·60	5·00*
	100·40	100·90
Metallic iron per cent.	21·56	22·39

* This analysis is erroneous. I have transcribed as given. There is a deficiency of 20 %. The number 5·00 should probably be 25·00.

[4] François, p. 296.

[5] Op. cit. p. 275.

These slags were very liquid, and were not magnetic. The oxygen of the silica is nearly the same as that of the bases, so that their formula is $3RO,SiO^3$.

Characters of the iron produced in the Catalan process.—It is described by François as in general fibrous, hard, very malleable, and particularly tenacious, but deficient in homogeneity. Its body is more or less charged with spots and grains of steel, which render it difficult to file or hammer. Moreover, owing to imperfect extrusion of the slag, it is apt to be unsound and deficient in malleability. François has given analyses of five varieties of iron produced in the Ariége, from which it would appear that the metal, with the exception of one, was nearly chemically pure iron, the percentages of iron being as follow: 99·9905, 99·9932, 99·9905, 99·9030, 99·9990: the other constituents are carbon, slag and silica, and manganese. I confess that these numbers not a little surprise me, and I am inclined to suppose there must be some mistake.

COMMERCIAL DETIALS.

In the table subjoined are presented the yields, charges of ore, and consumption of charcoal in 1841 at three forges in good working order.[6]

Name of Forge.	Average per Furnace in kilogrammes.			Average per 100 of Bar-iron.		
	Ore.	Charcoal.	Bar-iron.	Ore.	Charcoal.	Bar-iron.
Niaux-Vieux	510·20	460·04	168·00	300·30	273·80	100
Ramade	510·00	459·00	165·00	300·99	278·10	100
Celles	..	..	165·50	302·00	297·00	100

With the same ore the yields varied somewhat in different localities, according to the respective prices of ore and charcoal: thus, in forges near the mines charcoal might be dear and ore cheap, whilst in others at a distance from the mines charcoal might be cheap and ore dear, when, in the former case, charcoal, and, in the latter case, ore, would be economized as much as possible.

In 1839 and 1840, 49 furnaces in operation in the department of Ariége, in 38,200 *fires* or *heats*, produced 58,550 metrical quintals[7] of iron (about 5800 tons), selling at the forge at 43·5 francs per quintal; or, on the average, 779 fires and 1194 metrical quintals per forge. Of this amount of iron, 2150 metrical quintals, or $\frac{1}{27}$ of the whole, were natural steel (*fer fort*), which was in demand for agricultural purposes.

François has given the following balance-sheet of a forge at Vicdessos (Pyrenees) in 1840, making 1000 fires, and yielding 153 kil. of iron per fire.

[6] François, p. 50. The commercial details are chiefly from this author.

[7] A metrical quintal is 100 kil., and 1000 kil. about a ton.

COST OF PRODUCTION OF 100 KIL. OF BAR-IRON (FER FORGÉ) AT THE FORGE.

		Francs.
310 kil. of ore at 2 fr. per 100 kil.		6·20
302 kil. of charcoal at 8 fr. 20		24·76
Labour (*main-d'œuvre*)		5·95
A keeper of the forge, and a manager (*garde-forge et commis*), at 1500 fr. per annum		0·93
Repairs (*entretien de l'usine*), 1200 fr.		0·80
Interest at 5 % on plant, 25,000 fr.		1·03
Interest at 6 % on rolling stock as under (*fonds de roulement*), 29,000 fr.		0·98
For purchase of ore	3,000 fr.	
Do. charcoal	25,000 fr.	
Wages of workmen	1,000 fr.	
Cost of production of 100 kil. of iron (£1 13 10½)		40·65
Selling price at the forge in 1840 (£1 15 10)		43·00
Net profit (£0 2 2½)		2·65

The cost of production per ton of 2240 lbs. is	£17	4	1½
The selling price do. do.	£18	4	0
Net profit do. do.	£0	19	10½
The annual profit would, therefore, be nearly	£150	0	0

It will be observed that the labour alone upon the ton (2240 lbs.) of iron amounts to about 2*l.* 10*s.*, and the fuel to about 10*l.* Good bar-iron may now (April, 1862) be purchased at about 6*l.* per ton (English).

In the present day, with the existing facilities of steam communication by sea and land, and the enormous production of bar-iron well adapted for many of the purposes at least to which iron from the Catalan forges has been applied, and generally selling at a little more than a third the price above stated, it is evident that there can only be comparatively few localities in Europe where these forges can be conducted with profit. In mountainous regions, abounding in rich iron-ores and wood suitable for charcoal, and still inaccessible to railways, the Catalan process may hold its ground; but certainly not in localities, however advantageous with respect to ore, fuel, and water-power, where it is unprotected by high rates of carriage or other circumstances from competition with iron smelted and manufactured by modern processes. Its advantages are, that the outlay and floating capital required for a forge are inconsiderable, and the consumption of charcoal is comparatively small.

François makes some judicious remarks on the ignorance of the Catalan iron-masters, which I may insert with advantage. He writes, "There is ground for astonishment at the remuneration of the workman in our forges, remuneration which in the case of the head-men often reaches 8 fr. or more per day of labour. But on inspecting the forges it is soon perceived that the ignorance of the iron-master and his neglect of his establishment give rise to a certain extent to the pretensions of the workmen. Mention has often been made of the inutility of the man (the *foyer*) who has charge of the fire. I confess that he is not indispensable to an iron-master informed in the practice of his art. But in his present complete ignorance can he expect seriously to exert any influence over his forgers? He is under the law of the workman,

and will be so as long as he continues a mere dealer in iron, humiliates himself before the pretended omnipotence of routine, and repudiates the efficient co operation of applied science."[8]

The prejudice, obstinacy, and impracticability of the workmen in the Catalan forges are set prominently forth in the writings of Richard, François, and others, men understanding both the theory and practice of the art. Unhappily the workmen in our own iron-works have too frequently exhibited the same qualities, to the great injury of themselves and their masters. Even at the present day attempts at innovation in processes in operation would, in some localities at least, be certain to meet with fierce opposition from the workmen. This will not appear altogether surprising or unnatural when we consider that these men, having by dint of long practice and hard work acquired *special* skill, which commands a good price in the labour market, fear that innovations may diminish the value of their services. And, doubtless, innovations have in some instances occasioned great temporary distress to many industrious and deserving men. Nevertheless, resistance is utterly vain. If improvements are rejected in one locality, they will certainly take root and thrive in another. Numerous examples might be cited in which, through the obstinate and determined opposition of workmen to all improvements, a thriving manufacture has been annihilated in one town, but only to be transplanted and flourish with greater vigour in another. The moral is, that the workman should not hopelessly attempt to retard or check the irresistible law of progress, but should earnestly try to adapt himself to inevitable circumstances. Really intelligent and skilful men will find this to be the most prudent course, and in the long run they will probably have no cause to complain.

Improvements in the Catalan Process.

Utilization of the waste heat.—An account was published in 1850 of the successful application of the waste heat in some of the Catalan, or as they are termed Catalano-Ligurian, forges in Sardinia, of which there were as many as forty in operation in the province of Genoa.[9] They appear to have been established in this district at a very remote period, as no record of their origin had been preserved either in history or popular traditions. They resemble the Pyrenean forges in the form, dimensions, and construction of the furnaces, as well as in the use of the trompe. Even the Italian names of various parts of the furnace are similar to those of the French. The ore employed is obtained from the Island of Elba, and is described as "scaly compact specular iron."[1] An analysis of it made in the arsenal at Turin gave the following composition:—

[8] Op. cit. p. 337.

[9] Notices sur les usines Catalano-Liguriennes et sur les avantages récemment obtenus en utilisant les flammes perdues. Par C. Baldracco (traduit par MM. Jordano et Gastaldi). Ann. d. Mines. 4. s. 12. 1850, p. 143.

[1] Fer oligiste écailleux et compacte.

Protoxide of iron	1·61
Sesquioxide of iron	96·04
Magnesia	traces
Silica	2·15
Loss	0·20
	100·00
Metallic iron	68·51 %

It frequently contained visible traces of iron and copper pyrites, which were separated as completely as possible; and when no traces of these minerals could be detected by the eye, their presence was manifested by the odour of sulphurous acid evolved from the ore during roasting. Old cast-iron and wrought-iron scrap were treated along with the ore. The fuel was charcoal. The ore was charged in the manner previously described in the Pyrenean forges.

The following charges and yields are given :—

	1. kil.	2. kil.
Ore in lumps	190·68	222·32 (lumps and powder)
Ore in powder	47·65	
Cast-iron	23·82	25·82
Wrought-iron scrap	15·88	15·88
Charcoal	428·81	698·72
General yield of iron in square bars, requiring a further consumption of 135 kil. of charcoal in being drawn out into merchant bars	135·00	131·80
Iron in merchant bars		125·21

1. At the Tripalda and Prato forges. 2. At the Sassello forges.

It was at the Tripalda forge, where, during the greater part of a *heat*, 6k 60 of air were blown into a furnace per minute, that a flat-bedded reverberatory furnace was first constructed, so as to receive the flame escaping from a Catalan hearth, the long axis of the furnace being parallel to the line of the blast; and afterwards another similar reverberatory furnace was erected at the Prato forge, with the long axis at right angles to the line of the blast. One end of the furnace was connected with the Catalan hearth by means of a hood of masonwork at a convenient distance above, and directly over the latter. At the other end was a charging hole, immediately within and above which was a vertical chamber (which I will call C), having, like a fire place, a grate at the bottom and a door on one side, and terminating upwards in a chimney. The waste flame from the hearth was thus guided by the hood through one end of the reverberatory furnace, passed along over the bed, then rose perpendicularly through the grate into the chamber C, and from thence escaped into the chimney.

The ore was delivered at the forges in lumps as big as the head, or even larger. In this state it was strongly heated on the grate of the chamber C, when it evolved the odour of sulphurous acid, though no pyrites could be detected in it, even under a lens. After having been thus heated during some time it was withdrawn, and thrown while hot into water, by which means it was rendered easily fragile and porous, and lost about 5 % in weight. It was then broken into lumps

and coarse powder (*greillade*), and spread evenly over a layer of charcoal in fragments, with which the bed of the reverberatory furnace had been previously covered. The charcoal is essential, as shown by attempts to dispense with it. The ore, being thus exposed at a tolerably high temperature to contact with charcoal and to the reducing action of the gases of the Catalan hearth during the whole period of one heat, lost from 10 to 12% of oxygen. The bed of charcoal was entirely consumed in this operation. Some cast-iron and wrought-iron scrap was afterwards added to the ore, and the whole charge, while still hot, pushed regularly by means of a rabble through the charging hole into the hearth ready to receive it. By this preliminary treatment 5 heats instead of 4 could be worked off daily, with great economy in charcoal, improvement in the quality of the iron, and a little greater yield. It was necessary to prevent the reverberatory furnace from becoming so hot as to frit or fuse the ore.

In these forges there were separate furnaces for reheating the iron during the drawing out into bars, the waste flame of which was employed with great advantage in heating reverberatory furnaces; smaller, but in other respects similar to those already described, with the exception of the absence of the grate in the chamber C. The immediate result was great economy both of charcoal and time in the reheating of the iron.

Previously to the utilization of the waste heat of the Catalan furnaces the consumption of charcoal was 4·35 to 1 of merchant iron produced, whereas afterwards the relation was only 2·57 to 1.

The following results were obtained at the Tripalda forge after the adoption of the method of utilizing the waste heat:

Time employed.	Heats.	Raw Materials.					Iron obtained.
		Ore in lumps.	Ore in powder.	Cast Iron.	Wrought-iron scrap.	Charcoal.	
Hours.	Nos.	Kil.	Kil.	Kil.	Kil.	Kil.	Kil.
499	103	9813	6552	2454	3272	26,172	14,714

This is at the rate of about 4½ tons per week of 6 days of 24 hours each.

From the data in the preceding table it appears that by the improved method 30 heats instead of 24 as heretofore might be worked off per furnace in a week of 144 hours, *i.e.* in 6 days, with the consumption per heat of 95k 3 of ore in lumps, 63k 50 of ore in powder, 23k 80 of cast-iron, 31k 75 of wrought-iron scrap, and 254 kil. of charcoal, and with a yield of 143 kil. of iron of good quality in square bars. Besides, with a reheating furnace in which the waste heat was utilized in the manner described in the same establishment, 715 kil. of iron might be drawn out daily instead of 476 kil., as heretofore, during the same time.

Estimating the general annual expenses of a Catalano-Ligurian

forge at 3700 francs (about 150*l*.). and taking account of all expenses, the cost of production by the old method was 38fr 28, and by the new method 28fr 94, per 100 kil. of merchant bar-iron, *i.e.* in round numbers about 16*l*. and 12*l*. per ton respectively.

It will perhaps be considered by some persons that I have described the Catalan process at unnecessary length, because it is now defunct, or very nearly so, in Europe, and is not likely to be resumed. But surely the process by which all iron was formerly produced merits more than a passing notice on the ground of historic interest alone. There are, however, other reasons which have induced me to present a detailed account of this process. Such an account teaches much which will be found of value in our future inquiries, and may be useful to emigrants in some distant and comparatively inaccessible region, where the Catalan process might be carried on with advantage, and compete successfully even with British iron.

Corsican Process.[2]

This method presents several points of interest, and the apparatus which it requires is of the simplest kind, being in reality nothing more than a blacksmith's forge. It appears to have been practised in Corsica from a remote period. In 1812 there were eight of these small forges at work, in 1820 six, and in 1828 only four; but whether any still exist I am unable to state.

The ore employed was the well-known red hæmatite or specular ore of Elba. It reached Corsica in large lumps, and was carried on mules' backs to the forges without sensible loss. It was first heated in the manner hereafter to be described in order to render it more fragile, and afterwards broken in pieces by hand. The fuel was charcoal, made from the esculent chestnut tree. The blast was obtained with a *trompe* (tine) having one tree 7m 00 (23 ft. nearly) high. The hammer was of wrought-iron faced with steel; it weighed 144 kil. (317·5 lbs.), and was moved by a water-wheel. The anvil was of wrought-iron faced with steel; it weighed 80 kil. (176·4 lbs.), and was supported by a mass of cast-iron weighing 1000 kil. (about 1 ton.)

The hearth is represented in the accompanying engravings. It consists of a flat platform of mason-work, of which the top is at a convenient height from the ground, bounded in front by a little vertical wall, and on the left by a vertical wall containing the twyer; these two walls corresponding respectively to Nos. 1 and 2 sides of the Catalan furnace. In the front wall is a movable plate of iron (see fig. 24), in which is the tap-hole, 0m 50 (1 ft. 7·7 in.) from the left wall and 0m 56 (1 ft. 10 in.) from the vertical plane passing through

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[2] Vide Notice sur la fabrication du fer en Corse. Par M. Sagey, 1828. Ann. d. Mines, 2. ser. 4. pp. 121-144. Das Wichtigste aus der Eisenhüttenkunde von J. H. Hassenfratz. Leipsig, 1822, p. 324. Translation from the French by Hasse. There is also a special work on this subject which I have not yet seen; its title is, Mémoire sur la manière dont on extrait en Corse le fer. Par Du Coudray. Paris, 1775, 8vo. I derive my information from Sagey's paper, and some years ago I had the opportunity of conversing with the author on the subject.

the axis of the twyer, and 0^{m} 15 (5·9 in.) below the orifice of the latter. The twyer is a conical tube of copper; its *eye* or small end is circular, 0^{m} 031 (1·22 in.) in diameter; it is placed 0^{m} 50 (1 ft. 7·7 in.) above the top of the platform; its dip is 20°, and it projects 0^{m} 28 (11 in.). The top of the platform is always kept covered with a very thick bed of charcoal breeze.

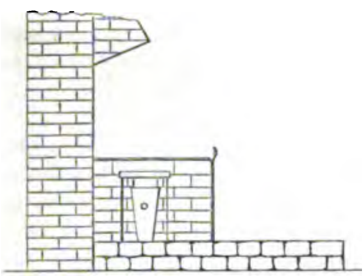

Fig. 24. Corsican furnace. Elevation.

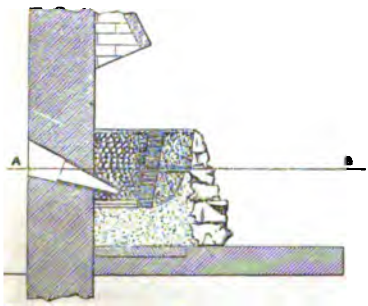

Fig. 25. Corsican furnace.
Vertical section on the line A B, Fig. 26.

Fig. 26. Corsican furnace.
Horizontal section on the line A B, Fig. 25.

As soon as the lump formed in the last operation had been withdrawn, the fire was extinguished by throwing water upon it; the large pieces of charcoal were taken out, and the blast let on in order to hasten the cooling; the mass in the hearth was stirred up, and any slag contained in it was carefully removed. A semi-elliptical cavity or basin was then made round the twyer in the residual moistened breeze, the bottom being 0^{m} 11 (4·33 in.) below the orifice of the twyer, and the great axis of the ellipse in the line from the tap-hole to what would be No. 3 side of a Catalan furnace: it was supported externally by a wall formed of large lumps of ore: see fig. 25. In this cavity, which I will distinguish by the name of breeze cavity, charcoal was piled, as shown in fig. 25, so as to form a well or vertical cavity widening upwards. Pieces of charcoal about 0^{m} 05 (2 in.) in diameter and about 0^{m} 16 (6 in.) long were selected for this purpose. The wall of ore supporting the breeze cavity was raised as high as the top of the well, smaller lumps being used for this purpose: see fig. 25. The space thus left round the exterior of the well of charcoal was divided into three compartments by vertical partitions of charcoal, built up *pari-passu* with the well itself; and the central one was the largest. Each of these was carefully filled with a mixture of ore broken in pieces and mixed with its dust, prepared as before described; and on a level with the top of the border of the breeze cavity at first formed there was interposed a horizontal layer of breeze: see

fig. 25. The heap of charcoal and ore thus raised was finally covered with breeze, and at the top it was 0^{m} 74 (29·14 in.) above the bottom of the breeze cavity. The weight of the charge of ore treated in one operation was 526 kil. (1160 lbs.).

The process was conducted as follows:—A few pieces of ignited charcoal were dropped into the well and covered with cold charcoal, and a gentle blast was then let on. The flame, which soon appeared, ceased after the lapse of about 40 minutes, when the workmen stated the ore to "be half-cooked" (à moitié cuit). The blast was now turned full on, and the well kept constantly full of charcoal. When the so-called "roasting,"—i. e. reduction of the ore,—had nearly ended, "several cakes of slag (scories douces) were withdrawn from a lateral basin very close to the hearth, pounded under a hammer, and spread out in a bed 0^{m} 02 (0·79 in.) thick along the edge of the hearth."

A few minutes after the last charge of charcoal the large lumps of ore forming the bottom of the outer wall were withdrawn, and taken to the place where they were to be broken up. During this period much water was thrown on the hearth. The mass forming the breeze cavity, and containing pieces of non-agglomerated ore, was withdrawn and spread over the layer of pounded slag. The agglomerated ore sustained itself round the well of charcoal; but that part of it above the horizontal bed of breeze (see fig. 25) was broken down with a rabble, and taken away piecemeal, the large pieces of charcoal were put in a heap, and the whole quenched with water. Thus the entire structure was demolished, and a mass of slag was found under the twyer. The ore was in great measure agglomerated.

The mixture of slag and breeze, forming a long heap on the hearth, was divided into 5 equal parts, each of which with the addition of $\frac{1}{5}$th of the agglomerated ore yielded one lump or massé (*massello*).

Care was taken, especially at the beginning of the process, not to raise the temperature so high as to melt the ore. Such an accident rarely happened; but when it did, the only thing was to break up the agglomerated ore and recommence the so-called "roasting." The charcoal consumed in "roasting" was about twice the weight of the ore. M. Sagey observes that it was a remarkable fact that the pieces of charcoal forming the cavity were very well preserved during the entire operation, and that the solidity of the structure was never endangered, notwithstanding the temperature was very high, and the amount of air blown into the hearth considerable.

The products of the operation described were *agglomerated ore* and *slags*, which filtered through the charcoal forming the base of the well and collected at the bottom of the breeze cavity. They are stated to have been produced by the fusion of a reddish clay existing in small veins in the Elba iron-ore. The characters of the slags, according to M. Sagey, were as follow:—well melted, glassy, transparent, and of a clear olive-green colour; they contained imbedded in their substance metallic globules of *cast-iron*, and a pretty large amount of fragments of charcoal, very thinly coated with metallic iron, which at first might not be distinctly visible, though it afterwards became manifest on rusting.

The agglomerated ore could be broken in pieces under the hammer; but most of these might with proper precautions be hammered out cold into thin sheets. It evidently consisted essentially of metallic iron.

It now remained to work up the reduced ore into lumps and to forge them into bars, and this was done on the same hearth as that employed in the operation above-described. Fresh dry charcoal dust from the charcoal store-house, and which had been previously freed by washing from earthy powder intermingled with it, was thrown upon the hearth and piled so as to form two inclined planes, meeting below the twyer in a horizontal line perpendicular to the twyer side: these inclined planes rose to the height of the little tap-hole wall in front. Ignited charcoal was put round the twyer, and cold charcoal underneath it; and upon the latter was placed a lump, which was then above the twyer. This lump was roughly cylindrical, and had a rod or staff of iron welded to one end in the direction of its long axis to serve the purpose of a handle. It was turned about at intervals, and, after the lapse of about 20 or 25 minutes, was taken to the hammer to be forged. While the forging was going on, a charge of the mixture of breeze, non-agglomerated ore, and pounded slag, previously mentioned, was introduced along with hammer-scales from the last forging into the middle of the hearth. This charge was left to itself, and the forging continued as though charcoal alone had been present in the hearth. Each of the five portions from the "roasting" part of the process yielded a lump from which four bars of iron were obtained.

The drawing out into bars lasted somewhat less than 2 hours from the time the blast was let on. The management of the fire consisted in supplying charcoal as fast as it was consumed, throwing water over the fire, and keeping the twyer free and open. In heating a lump of iron for forging, it was always placed in front of, and a little above, the twyer, so that the blast might not impinge directly upon it and occasion unnecessary waste by oxidation.

An hour and a half after the beginning of the operation the tap-hole was opened, when very liquid slag escaped, which was received in a breeze cavity quite close to the tap-hole. Half of the agglomerated ore was now placed in front of the bed of breeze constituting the hearth proper and nearly at the height of the twyer, and in 5 or 6 minutes afterwards it was pushed horizontally towards the centre. Being now exposed to a high temperature, it softened, and at some points even melted into drops, until at length, partly from this cause and partly from the burning away of the charcoal underneath, it had descended below the blast, where it became united to the non-agglomerated ore previously charged.

The other half of the agglomerated ore was put into the place previously filled by the first half and treated in the same manner. Slag (scories douces[3]) was thrown at intervals into the hearth. When the

[3] So called by Sagey because the workmen stated that they had the effect of softening the iron.

lump was perfectly formed, about a pound weight of hammer-scales with a little less of the powder of the ore was thrown in, "probably," M. Sagey remarks, "to complete the decarburization of the iron." A few minutes afterwards the blast was stopped, water was thrown in, and the lump taken out. The lump was freed from the cake of slag adhering to it underneath, and beaten with a wooden mallet, and the iron staff to be used as a handle during the forging was welded to it.

The thin layer of slag which first solidified on the surface of that which flowed from the tap-hole and had been received in the breeze cavity prepared for the purpose, was taken off and thrown away, as being of bad quality; but the remainder, which afterwards solidified, was preserved and worked over again. The cause of the alleged inferiority of the upper stratum was not investigated; but it was conjectured that it might be sulphur.

The duration of the "roasting" and the working up of the five portions of reduced ore, etc., in the manner described was exactly 24 hours, the workmen being allowed 4 hours for each portion. Only four workmen were required in a forge, and they laboured 6 days in the week. The forges were only in operation during 7 months of the year, the excessive heat and occasionally the insalubrity of the atmosphere compelling them to cease working at the end of June. During this period not more than 260 metrical quintals (about 26 tons) of bar-iron were made on the average. The iron produced was reputed of excellent quality, "ductile and very fibrous, without being malleable like that of Sweden; it could be forged well both hot and cold without cracking." The cost of production of bar-iron at one forge, making annually 290 metrical quintals, was 46·31 francs, and at another, making annually 250 metrical quintals, 51·20 francs per metrical quintal, i. e. in round numbers, 19*l.* and 21*l.* per ton, respectively. The average yield of bar-iron from the ore was only 38·66 %. The consumption of charcoal for 1 part by weight of iron could not be estimated at less than 8·88 parts by weight of charcoal.

The consumption of charcoal in this old Corsican process was enormous; and in this respect it teaches us a valuable lesson. It is, I conceive, very important that defective metallurgical processes should be fully recorded, as well for our warning as our instruction. After the detailed description which has been given of the Catalan process, I have not considered it necessary to enter at length upon the theory of that of Corsica. In both the chief reducing-agent is clearly carbonic oxide; and the mode in which the charcoal and ore are arranged in the Corsican process is obviously such as to favour the formation of this reducing-agent and its contact with the ore. It is curious to note how in the course of experience efficient processes are gradually developed, in entire ignorance of the principles upon which they are founded.

Iron-smelting in the Stückofen (German).

Under the head of Indian iron-smelting, allusion has already been made to this furnace, for which there is no English name, but which

might be called the *high bloomery* furnace, as it is only a Catalan furnace extended upwards in the form of a quadrangular or circular shaft. The Germans designate it Stück- or Wolfsofen, because the large metallic mass which is extracted from the bottom is termed Stück or Wolf. The transition from the old bloomery to the modern blast-furnace was very gradual, and the Stückofen is the final development of the furnaces in which iron in the malleable state was produced direct from the ore. By increasing the dimensions of the Stückofen, especially its height, the conditions favourable to the formation of cast-iron are obtained; and, indeed, in the Stückofen cast-iron was generally, if not always, produced in greater or less degree, to the annoyance of the smelter. Between the Luppenfeuer, or Catalan furnace, and the Stückofen, German metallurgists place a furnace of intermediate height, which they designate Blaseofen and Bauernofen.[4] This furnace was formerly employed in Norway, Sweden, and other parts of Europe; and although a century may have elapsed since it became extinct in the first two countries mentioned, yet to this day it continues in operation in Finland. I shall distinguish it by the name of the Osmund furnace, from the Swedish word *osmund*, which was applied to the bloom produced in this kind of furnace.

The Osmund Furnace.

I am indebted to my friend Mr. Andreas Grill for information on this subject. In 1732 the Royal Board of Iron Trade directed one of their mining surveyors to prepare an accurate description of the osmund process, which at that time was only practised in one county in Sweden, and this he accordingly visited for the purpose. His description was illustrated with an original drawing, representing the furnace, the implements employed, etc.; and from a tracing of this drawing, with which Mr. Grill has provided me, the accompanying engravings have been executed. Swedenborg in his large volume on Iron has given an account of the osmund furnace, which he acknowledges having derived from a description by a Swede named Peter Laxholm;[5] and he has also introduced an engraving, which in all essential particulars is identical with the tracing communicated to me by Mr. Grill, and which doubtless was copied from the same original drawing.

Description of the Engraving, fig. 27, *as stated in the original Drawing.*

A. Heap of bog-ore, not calcined. B. Calcining heap, on wood. C. Heap of calcined bog-ore. D. Earth-borer to search for ores. E. Charcoal-rake. F. Iron-shovel. G. Tongs for drawing the osmund bloom out of the furnace. H. Cinder-hook, used also in taking out the bloom. K. Bar for cleaning the cinder-hole and twyer-hole. L. Large sledge, used to hammer the bloom when first taken out. M, M. The lump of iron, "blästra," or osmund, partly cleft. N. The hatchet. O. The treadles to work the bellows.

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[4] Lehrb. der Probir-u-Hüttenkunde. Wehrle. 1814. 2. p. 116.

[5] Regnum Subterraneum sive Minerale. 1734, p. 119.

P. Bridge of wooden planks. Q. Tap-hole for the cinder. R. Twyer. S. Wooden shovel for charging ore into the furnace.

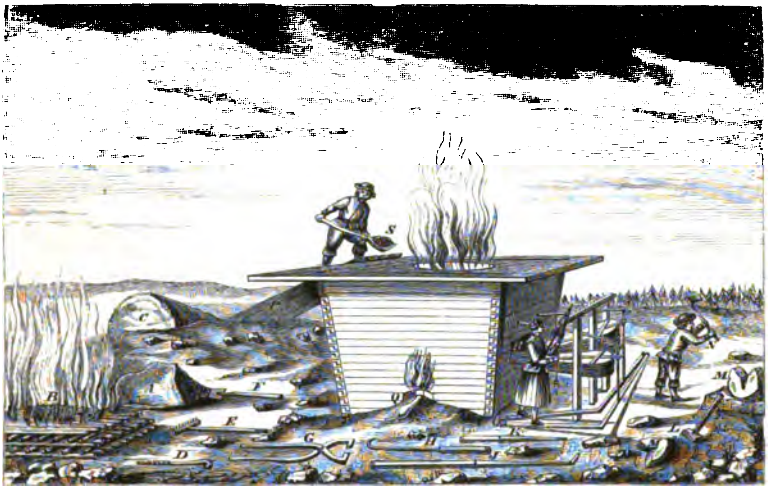

Fig. 27. Osmund Furnace. From an old original drawing.

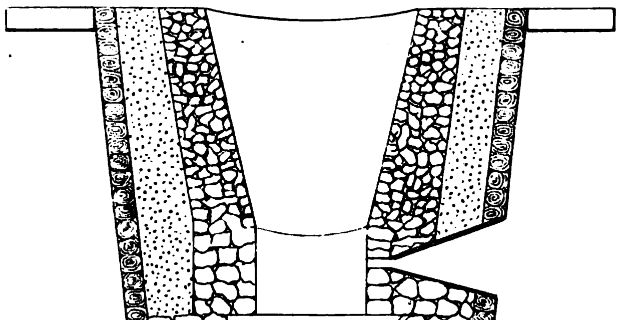

Fig. 28. Osmund Furnace. Vertical section through the twyer. Copied from Swedenborg's plate.

The ore treated in the osmund furnace was bog iron-ore, which consists essentially of hydrated sesquioxide of iron. Concerning the mode of occurrence and extraction of this ore Swedenborg gives a detailed and interesting account, from which I abstract the following particulars.

Everywhere in Sweden, both north and south, the ore was extracted from the bottom of the lakes and rivers. It was designated lake iron-ore (*vena lacustris ferri*). That in Angermannia (an old province in Sweden) was described as uneven in shape, or sponge-like, of a brown colour (*coloris bruni*), friable under pressure between the fingers, and in fracture resembling cut leather; it occurred in detached portions of

variable form, and sometimes of the width of the palm of the hand, and in round grains of the size of grains of barley or wheat, or even of beans; it was not found far from the shores, and it was reproduced in the course of 20 or 30 years. During summer the ore was collected in boats by means of drags; and during winter it was raked up through holes made in the ice. Through the whole of Småland are lakes from which this kind of ore was extracted, and converted in furnaces in the usual manner into crude iron. So great was the quantity of this ore in Småland and the neighbouring provinces, that an ample supply might have been obtained for numerous furnaces; and, as Swedenborg quaintly expresses it, "hic Mars uvidus amat fundos lacuum." When dry it was light and porous, as though it did not contain much metal; and yet it yielded a large quantity. The ore varied greatly in richness and in quality, one kind producing the worst and another the best description of iron.

In the Swedish department of the International Exhibition of 1862 there was an interesting collection of lake-ores, accompanied with an explanatory pamphlet by C. W. Sjögréen, from which the following information is extracted.[6]

These ores are found chiefly in the lakes and streams in the province of Småland, and as many as five varieties of them are described. They have a concretionary structure, and are designated according to the resemblance of their particles in form and size to certain familiar objects. The varieties are as follow:—1. *Pearl-ore.* It yields 45 % of iron, is very hard and heavy, and presents a dark-brown, oily, shining fracture; it occurs chiefly on muddy or clayey bottoms. 2. *Bur-ore.* It is called after the head of the burdock; it is somewhat spongy, very light, and seldom yields more than 30 % of iron; it breaks easily, and crumbles on drying; it is principally found on grassy bottoms. 3. *Money-ore.* It is in small, round, coin-like cakes; it is more dense than either of the first two; its fracture is similar to that of pearl-ore; it yields as much as 40 % of iron. 4. *Cake-ore.* It is in the form of round cakes of from 2 to 6 inches in diameter, soft, very light, and dark grey; it is considered very poor, not containing more than 25 %, and is, consequently, seldom employed; it is found on gravelly or clayey bottoms. 5. *Gunpowder-ore.* It is in grains varying in colour from greenish-yellow to shining black; it is very heavy when pure, and may yield as much as 50 % of iron, which is well adapted for casting; it rests on a bottom of fine sand, which it is sometimes nearly impossible to separate from the ore after it has been taken out of the lake.

Lake-ores are always more or less intermixed with impurities, of which the chief is sand, sometimes to the amount of 30 % or 40 %. They contain from 20 % to 60 % of sesquioxide of iron, and protoxides of iron and manganese, as much as 10 % of silica, from

[6] On the Swedish Lake-Ores, in illustration of samples sent to the Great Exhibition in London, 1862. By C. W. Sjögréen. Ekesjö, 1862. See also Beiträge zur genaueren Kentniss des Eisenhüttenwesens in Schweden. Von Dr. Moritz Meyer. Berlin, 1829, pp. 191-5.

0·05 % to 4 % of phosphoric acid, and from 7 % to 30 % of hygroscopic water. At one place lake-ore is found which contains 20 % of manganese.

These ores are universally found in the neighbourhood of reed-banks and on the slopes of the shallows in the larger and deeper lakes in layers from 10 to 200 yards in length, from 5 to 15 yards in breadth, and from 8 to 30 inches in thickness. They never occur in strong currents of water. The same variety is never met with throughout the whole stream: thus, as a rule, gunpowder-ore will be found at the beginning, then pearl-ore, and lastly money and cake-ore. Within a short time lake-ore is reproduced, and there are instances of lakes where the ore, after having been completely exhausted, collected again in the course of 26 years to such a degree as to form beds several inches in thickness. The ores are supposed to be of infusorial origin.

The mode of collecting the ore merits description. Towards the end of autumn, when the lakes have become icebound to the depth of 2 or 3 inches, the collector proceeds to search for ore. With this view he introduces a long pole through little holes made in the ice along the slopes of the shallows, and gently strikes the bottom, when, partly by the sound and partly by the touch, he ascertains whether ore is present or not; and he requires long practice in order to perform this work with success. The ore-collector marks the boundaries of the bed of ore which he thus discovers with little twigs stuck in the ice, and so acquires legal possession of it. In this manner he marks out as many places as he proposes to work during the winter. When the ice is strong enough, he makes a hole in it about 3 ft. in diameter at the outer boundary of the marked claim, and through this hole lets down to the bottom a riddle of perforated iron plate fixed to a long pole. Then, by the use of an iron rake about 2 ft. broad, also fixed to a pole, he collects the ore into a heap at the bottom, and with another rake about 6 in. broad he fills the riddle, which is taken out and emptied of its contents upon the ice. The ore in this state is mixed with mud, clay, and sand; and in order to separate these it is put into another iron riddle, which is sunk 2 in. or 3 in. below the surface of the water, and receives a rocking motion, whereby the impurities pass through the riddle, leaving the ore comparatively pure. Two men are generally associated in this work, one being employed in collecting and the other in washing the ore. If the ore is tolerably plentiful, a man generally collects from half a ton to a ton in a day; but this will obviously depend, not only on his skill, but also on the nature of the ore and the character of the bottom of the lake. In the province of Småland during the greater part of the winter the occupation of ore-collecting is extensively carried on.

In 1855 the total amount of lake- and bog-ores collected in Sweden was 290,000 ctrs., or, in round numbers, between 14,000 and 15,000 tons,[7] and in 1860 it was about 22,000 tons.[8]

[7] Das Eisenhüttenwesens in Schweden. P. Tunner. Freiberg, 1858, p. 12.

[8] Swedish Board of Trade Report for 1860. Published Sept. 18, 1861.

By way of illustration I insert the following analyses of bog iron-ores from different localities.*

	1.	2.	3.
Silica	9·20	8·12	7·00
Phosphoric acid	10·99	3·44	0·67
Sulphuric acid	..	..	3·07
Sesquioxide of iron	51·10	62·92	67·46
Peroxide of manganese		4·18	3·19
Alumina	0·41	4·60	..
Lime	..	..	0·90
Water	28·80	18·40	17·00
	100·50	101·66	99·29

1. From Leipsic. Yellowish-brown. By O. Erdmann. 2. From Schleswig. Sp. gr. 2·432. By Pfaff. 3. From Auer, Moritzburg. By Bischof. The proportion of phosphoric acid is extremely small, and must be quite exceptional.

ANALYSES OF SWEDISH LAKE AND BOG ORES BY PROF. L. F. SVANBERG.

	PO^5.	SO^3.	CaO.	MgO.	Al^2O^3.	SiO^3.	Fe^2O^3.	Mn^2O^3.	Water, Organic Matter and loss.
Lake ore from Neij, Calmare county	1·128	trace	0·823	0·149	5·088	7·146	65·576	3·871	16·219
Lake ore from Hulingen, Calmare county	0·701	trace	0·615	0·162	7·894	7·376	68·823	0·640	13·789
Lake ore from Yxern, Calmare county	0·559	0·119	1·821	0·064	3·469	5·854	69·953	1·974	16·187
Lake ore from Auern, Calmare county	0·259	0·031	2·344	0·088	3·096	8·536	56·475	15·881	13·290
Lake ore from Widöstern, Jönköpings county	0·825	trace	2·265	0·731	5·261	8·018	68·448	3·075	10·727
Lake ore from Örssjö, Kronobergs county	0·434	trace	0·677	0·135	2·167	10·697	57·081	16·185	12·924
Bog ore from Åminne, Jönköpings county	0·253	0·127	2·683	0·021	2·359	41·258	45·260	0·463	7·576
Lake ore from Fyllern, Jönköpings county	0·168	trace	0·674	0·236	4·379	6·399	60·863	11·501	15·780

With reference to the construction of the osmund furnace a few observations only are required in addition to the accompanying woodcuts. In Swedenborg's engraving there is a horizontal section through the middle of the twyer, and from this it appears that at the bottom there was an oblong rectangular cavity to receive the lump of reduced iron. There was a large opening into the interior of the furnace near the tap-hole, Q, through which the lump was extracted, and which during the working of the furnace was built up temporarily with stones. The inner lining of the furnace was made of refractory stone, and the space between this lining and the timber casing on the outside of the furnace was filled with earth.

The ore, after having been dried by exposure to the air, was cal-

* Nos. 1, 2, 3, from Rammelsberg's Handb. d. Mineralchemie, 1860, pp. 153-4.

cined in heaps, with wood as the fuel; and the calcination was completed in two days. The calcined ore was smelted with charcoal, and the same succession of operations was practised which have already been so fully recorded as to render further description superfluous. The lump was sufficiently pure to admit of being at once forged into various articles; whereas any pieces left after the extraction of the lump were so impure that it was necessary to subject them to a second heating process, and expel the impurities by more powerful hammering.[1]

Not more than 1½ ton of iron could be made weekly in one of these furnaces; and in working up the osmund or bloom there was a loss of from 33 % to 50 %. It is especially worthy of remark that, notwithstanding the presence of a large amount of phosphorus in the ore employed, the osmund furnace yielded good malleable iron; whereas the iron obtained from such ores by the usual method of producing cast-iron in the first instance and subsequently converting it into malleable iron is cold-short and bad.

It has been previously stated that the osmund furnace is still in operation in Finland; and this is a fact of considerable interest, which is not, I believe, generally known to metallurgists. But a still more interesting circumstance is, that it maintains its ground side by side with a modern blast-furnace. The ore treated is the so-called lake-ore; and it is only by means of the osmund furnace that good iron can be made from this ore, the reason, no doubt, being that the phosphorus in the ore does not pass into the iron, but remains in the slag. Information on this old method of extracting iron is contained in a pamphlet recently printed in Stockholm,[2] from which I subjoin the following details.

In the north and north-west of Finland, especially in the county of Wiborg and the neighbouring parts of Kuopio, much lake-ore is smelted in peculiar furnaces called "harkhyttor," a name derived from the Finnish word *harkko*, meaning piece, lump, and from the Swedish word *hytta*, meaning furnace. These furnaces are described as consisting of a shaft about 3 ells, or 6 English feet, in height; and the mass of reduced iron, it is stated, may be malleable, though more frequently it is only a mixture of raw and malleable iron, and must be re-melted in a refining hearth.

The lake- and bog-ores of Finland are smelted in high blast-furnaces, as well as in the low "harkhyttor;" and occasionally, as at Warkaus, in the district of Kuopio, both kinds of furnaces occur standing side by side, with the addition of a forge for making bar-iron. The cast-iron produced from lake- and bog-ores in the high furnaces is chiefly intended for foundry purposes, and is sent to St. Petersburg. The low furnaces are peculiarly adapted for the production of wrought-

[1] Ut autem, si quæ residuæ sint, impuriores adeoque inutiles particulæ fortiori Vulcani ministerio expellerentur, alteri coctioni eadem destinabatur quantulacunque moles. Op. cit. p. 119.

[2] For a copy of this pamphlet I am indebted to my friend Mr. Grill. The title is "Några Ord om Finlands Bergshandtering. Af L. J. Igelström." Stockholm, 1861. Remarks on the mining trade of Finland.

iron from these ores, for the reason above assigned respecting cold-shortness due to phosphorus. Thus, a low furnace at Pangakoski in the district of Kuopio produces yearly from lake-ores 100 tons of wrought-iron, which is regarded as extremely good, and is partly worked up into nails on the spot.

The number of low or "hark" furnaces in Finland is as follows:—

Name of county.	Number of furnaces.
Kuopio	13
Uleaborg	6
Abo	2
Wasa	2
Tavastehus	2
Total	25

I cannot better conclude the subject of the osmund furnace than by presenting some pertinent comments upon it by my enthusiastic metallurgical friend Mr. Grill. "Is it not," says he, "beautiful to see the simple yet efficient way in which everything is carried on [referring to the illustration of the process, fig. 27]? When the peasant had finished his field-labour for the season, he went into the woods for some weeks with his family to make a little money by extracting iron, which in winter he carried for sale to the market-places. The locality represented in the engraving is not more civilized than Hudson's Bay. The man with a beard was one of the Dalecarlian peasants, who, as far as tradition extends, have been reputed good bow-men. The female is a pattern of industry, her hands being engaged in spinning with the old distaff, and her feet in working the bellows." I confess that these old metallurgical processes have a peculiar charm for me, due in part to the interest with which antiquity invests bygone things, in part to the picturesque scenery amidst which many of the old works were established, and in part to the reflection that something which has done good service in its day has gone for ever.

The Stückofen or High Bloomery Furnace.

This furnace, as has been previously remarked, is the final development of the furnaces in which malleable iron is directly produced from the ore, and may be regarded as the lowest development of the modern blast-furnace. Indeed, the conditions presented by this furnace are so favourable to the formation of cast-iron, that the metallic lump is occasionally carburized to such a degree that it must be subjected to a decarburizing process before it can be worked under the hammer. Formerly these furnaces were in operation in various parts of Europe, especially in Carniola, Carinthia, and Styria; but Karsten, in 1841, stated that on account of their great consumption of fuel they had been entirely abandoned, though they were still in operation in Hungary, and to a limited extent also in Germany, in the district of Henneberg.[3] Descriptions of this furnace and of the manipulations

[3] Karsten, Handb. d. Eisenhüttenkunde, 1841, 3, p. 34.

connected therewith will be found in all the old metallurgical treatises; and one of the best which I have met with is given by Jars in his account of the iron-works at Eisenerz, at the foot of the Erzberg in Styria.[4]

By way of illustration I have selected the following description of a characteristic Stückofen formerly in operation in the vicinity of the town of Schmalkalden, in Hessen-Cassel, where spathic carbonate of iron and brown hæmatite occur.[5] One of the localities of these ores at a short distance from the town derives its name from their presence, and is called Stahlberg, or Steel-mountain. Iron and steel works appear to have been established in this district during a long period.

The form of the interior of the furnace was that of two truncated cones with their broad ends or bases in contact. The total height of this furnace was 16 ft., but there were two others only 12 ft. high each.[6] The diameter at the bottom was 2½ ft., at the top or mouth 1½ ft., and at the widest part, which was exactly in the middle, or 8 ft. above the bottom, 4 ft. 2 in. The furnace was carried up a few feet higher than the mouth, gradually widening for the sake of greater convenience in charging. There was one twyer, and it was placed 14 in. above the bottom; but, in the course of long working, the bottom or *hearth-stone* became so much corroded away that it was 20 in. above the bottom. It is stated that this variation in the distance between the twyer and the bottom had an extraordinary influence upon the yield, the quality of the product, and the consumption of charcoal. The twyer, which was made of copper, was horizontal, and projected 3 in. into the furnace. The hearth-stone was a siliceous conglomerate, and sloped 2 in. or 3 in. towards the drawing-hole through which the metallic lump was extracted. This hole was 2 ft. wide, and before the smelting began was stopped up with bricks and clay. The blast was produced by bellows moved by a water-wheel.

According to Karsten the height of these furnaces varied from 10 ft. to 16 ft. In some the shaft increased regularly in width from top to bottom; but in most it bellied out in the middle: it was either round or quadrangular. In some of these furnaces, as at Eisenerz, the blast was introduced on the drawing-hole side, in which case it was necessary to remove the bellows every time before the extraction of a lump.[7] The twyer was usually made of clay, and rarely of copper, and there was nothing definite as to its width. Jars describes how they were fashioned at Eisenerz. A brick-

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[4] Voyages Métallurgiques, 1774, 1, p. 37 et seq.

[5] I have derived the materials for this description from the following work:—Praktische Abhandlung über die Eisen- und Stahlmanipulation in der Herrschaft Schmalkalden von Johann Christian Quantz, Hüttenschreiber zu Lerbach. Nürnberg, 1799, p. 28 et seq. The town of Schmalkalden was contained in the county of Henneberg, before the subdivision of the latter. Karsten has evidently availed himself largely of this work in describing the Stückofen.

[6] I have not considered it necessary in this description to give the corresponding English measures, as the difference between them is too small to be of any practical importance.

[7] Jars. Op. cit. 1, p. 38.

like lump of tempered clay, about 4 in. thick, was placed in the centre of the drawing-hole, and projecting about 10 in. into the interior of the furnace. By the side of this lump were placed other lumps of clay, 8 in. or 10 in. broad, but only about 2 in. thick; the joints were stopped with clay, and a hole was then made with a pointed rod of iron through the large lump, which became thereby converted into a twyer. This hole was about 3 in. wide on the outside and 1½ in. on the inside of the furnace, and was about 12 in. above the bottom.[8] In some places the tap-hole for slag was at first made lower than in the furnace described, and raised, together with the twyer, *pari passu* with the increase of the metallic mass at the bottom.

In commencing a smelting operation, the drawing-hole having been closed in the manner described, the furnace was filled with charcoal, which was ignited through the twyer. The bellows were worked a few times and then stopped, so that the charcoal might be slowly kindled and the furnace heated by degrees. As soon as the fire had reached the top, the blast was again let on, and the charging with charcoal and iron ore commenced. At first only little ore was added; but the proportion was gradually increased until the proper relation between the charcoal and ore was attained, that is, about 4 measures of the former to 1 of the latter. The slag was tapped off through an aperture made in the "stopping" of the drawing-hole, and this was kept constantly open. That which first appeared on the hearth, when it contained only a small quantity of iron, was taken away, stamped, and washed in order to separate any particles of metallic iron which might be diffused through it, and which, according to Karsten, were shots of cast-iron. But when the mass of iron in the hearth became considerable, it was kept hot by allowing the slag to accumulate in front of the drawing-hole; for, otherwise, it was much more difficult to detach, and great damage might be done to the furnace, which, indeed, sometimes happened in any case. When the proper amount of iron had collected in the hearth, as the smelter ascertained by probing through the twyer, the charging was discontinued and the furnace allowed to go down, or a few charges only of charcoal were supplied, and the slag in front of the drawing-hole was quenched with water and carried away, after which the hole was opened, and the mass of iron after having been loosened from the sides and bottom of the furnace extracted. It occasionally happened that the mass had undergone incipient fusion and become firmly adherent to the bottom of the hearth, in which case the furnace was allowed to cool down somewhat and the mass detached as best could be done.

This operation must have been very laborious. Jars has given a detailed account of it, as conducted at Eisenerz, where the lump was grasped by large pincers and pulled out by means of a chain passing round a vertical cylinder in connection with a water-wheel.

As soon as the lump was withdrawn, it was everywhere covered with a large quantity of charcoal dust to protect it from superficial

[8] Op. cit. p. 40.

oxidation by atmospheric air, and to keep it hot. The lump was worked under the hammer, which at first was only allowed to go gently, into a round cake about 3 in. or 4 in. thick; this was cut into two pretty equal parts,[9] which were subdivided and drawn out under the hammer into bars in the usual manner. Eight men were required for the operation of working up the lump by hammering, cutting, etc. At Eisenerz, according to Jars, the lump was first cut half through in the centre with hatchets by two men, each having one. It was afterwards completely divided by means of wedges and large hammers.

A lump weighed from 4 to 6 centners (say from 4 to 6 cwts.), and required for its production from 216 to 234 cubic feet (say about the same as English feet) of charcoal. On an average three such lumps were made in a day, or from 60 to 70 centners in a week. At such a furnace as that described, 3 men were employed at a time in shifts of 8 hours each. No work was done on Sunday. At Eisenerz the lump was much larger, and weighed from 13 to 14 quintals; but there the hearth of the furnace was also much larger, being 4 ft. wide and 2½ ft. deep, opposite the twyer. In addition to the lump proper there were obtained from 6 to 7 quintals of iron, which, Jars states, *flowed* out of the furnace, and which, therefore, were steel or cast-iron. Thus 20 quintals in all of iron and steel were obtained in a single operation which lasted 18 hours, 15 being required to produce the metal and 3 to draw it out, cut it, and prepare the furnace for the next operation.[1] This preparation consisted in cleaning out and repairing the hearth, and covering the bottom with a level and solid brasque of moistened charcoal powder.

The metal forming the lump produced in this process was described by Quantz as soft, tough, and malleable, though less so than bar-iron; he considered it as intermediate between cast and bar-iron, yet nearly approaching the latter.

In the Henneberg district the process of making malleable iron direct from the ore in the Stückofen was gradually superseded by the modern cast-iron process. But, as the demand for Stückofen iron continued after the introduction of the latter process, it was supplied by employing the same furnace for the production of both descriptions of iron.[2] The furnaces which replaced the Stückofen were called Blauofen,[3] and originally there was no essential difference between them, these names being applied according to the nature of the metal which they yielded, and not in consequence of difference in construction. Hence, nothing could have been more gradual than the development of the modern blast-furnace in which cast-iron alone is obtained.

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[9] According to Quantz (op. cit. p. 36), these parts were called "Stücke," and gave the name to the furnace. The entire mass was termed "Guss:" but this was an improper appellation, inasmuch as the lump was never actually melted.

[1] The quintals may in this case be estimated as English cwts.

[2] Vide Bemerkungen über den Betrieb der Stücköfen im Hennebergischen. Karsten's Archiv. 1. ser. 1824, 8. p. 239.

[3] I do not know the derivation of this word. In the French translation of Lampadius's Handbuch it is termed "fourneau bleu," or blue furnace. (Manuel de Métallurgie, etc. Paris, 1840, 2. p. 123.)

When the Blauofen was used as a Stückofen, it was only necessary to make an opening in the fore-part of the hearth large enough for the extraction of the lump. The twyer side of the hearth was formed by a mass of iron, such as an old anvil, to prevent its being injured during the drawing out of the lump; and the drawing-hole or opening in the fore-part was stopped up either with bricks or pieces of moulded slag, the joints being closed by packing in pieces of brick and plastering up with clay. The twyer was made to project as little as possible into the interior of the furnace, so that it might not be easily shifted from its place during the extraction of the lump.

By far the greatest part of the iron-producing materials employed was rich iron slag formed in the process of converting cast into malleable iron; but to this was added hammer-scales obtained in forging, and occasionally red hæmatite to the extent of never more than $\frac{1}{4}$th of the whole.

The condition favourable to the formation of cast-iron is prolonged contact of the reduced metal with carbon at a high temperature; and this is secured by increasing the proportion of charcoal relatively to the iron-producing materials. Hence, in order to obtain malleable iron, the proportion of charcoal was relatively diminished; or, in other words, the furnace was made to carry a heavier *burden*. But one essential condition in working the furnace as a Stückofen was to allow the slag free escape during the process, so that the lump of iron accumulating in the hearth might never be covered with slag and so be protected from the action of the blast.

I insert side by side Karsten's analyses of a specimen of the rich slag treated and the slag accompanying the formation of the lump and tapped off as previously described:—

	1.	2.
Silica	11·10	29·1
Alumina	0·09	4·3
Lime	0·13	2·6
Magnesia	1·05	9·2
Protoxide of iron	84·30	51·7
Protoxide of manganese	2·80	2·9
Alkali	trace	trace
	99·47	99·8

In slag No. 2 the ratio between the oxygen of the silica and that of all the bases is nearly as 5 : 6. These analyses are instructive as showing the very large amount of iron which escaped in the slag, a condition which is favourable to the production of iron of superior quality.

Clay's Process.

I am indebted for the following description to my friend, Mr. Denham Smith, who was himself engaged in conducting the trials on a large scale to be hereafter described. Although the process was not successful, yet it is important that the results should be placed on record, as success, especially in metallurgical operations, has seldom been attained except after repeated failures.

"The capability for welding of crude spongy metallic iron obtained by heating rich hæmatite in powdered charcoal was the gist of patents taken out by William Neale Clay,[4] wherein he proposed to make wrought-iron direct from the ore without the intervention of the blast-furnace. The process was most simple: the better kinds of red hæmatite iron ore were to be crushed to lumps not larger than a walnut, and these, mixed with one-fifth of their weight of charcoal, coke, coal-slack, or other carbonaceous matter, were subjected to a bright red heat, in a clay retort, or other suitable vessel, until the ore should be reduced to the metallic state. When the reduction was complete, the spongy iron was transferred direct to a puddling furnace, with or without the addition of some five per cent. more coke, where it was 'balled,' and then wrought into 'blooms' under the tilt-hammer, which blooms were rolled and formed into merchantable iron in the usual way.

"This plan for making wrought-iron direct from the ore was tried experimentally at a small forge near Glasgow, and afterwards on a larger scale at Liverpool. Commercially speaking, it proved a complete failure. Iron was made, and, at times, iron of most excellent quality, possessing very great tenacity, especially fitted for cable-iron; but it was not uniform, and was frequently so 'red-short' that the smiths refused to work it. The chief source of failure, however, was the length of time required for reducing the ore, and the consequent expenditure of fuel and labour in this part of the process, together with the number of retorts or reducing kilns, with the wear and tear of these, required to keep at work the puddling furnaces of even a small forge.

"It was then attempted to effect the reduction of the ore, directly, in the puddling furnace; but here, again, the expenditure of time, fuel, and labour, together with the waste of ore in the shape of cinder, compared with the amount of iron obtained, was so great, that this process was quickly abandoned for a modified one, whereby pig-iron was used in the puddling furnace, together with a mixture of hæmatite ore and carbonaceous matter. This last method was partially adopted at some few forges in the North of England, especially in one at Workington, which was taken solely for the purpose of carrying it out. After many preliminary trials, it was found that a mixture consisting of dried hæmatite, ground so as to pass through a ¼ inch riddle, with about one-third of its weight of coal-slack, washed in a solution of soda-ash or brine, that which floated only being used, was best fitted for smelting in conjunction with pig-iron in the puddling furnace. To the mixture of hæmatite and slack there was usually added about 4 lbs. of fire-clay, 4 ounces of soda-ash, and 6 ounces of common salt to each 112 lbs. of ore, an addition which experience seemed to show was beneficial both in making the cinder more liquid, and the 'blooms' to roll softer and smoother than when these fluxes were

[4] Mr. Clay obtained two patents: the first A.D. 1837, Dec. 19, No. 7518; and the second A.D. 1840, March 31, No. 8459.

omitted. So much of this mixture as was equal to 1 cwt. of hæmatite was thrown in a heap on to the bed of the puddling furnace, and after being heated for about 20 minutes with the damper down, the remainder of the charge, consisting of 4 cwts. of pig-iron, was piled around the heap. The pig-iron in melting assisted in the reduction of the oxide of iron, and when this was effected the puddler worked his 'heat' in the usual manner. Just before 'balling,' it was found advantageous to throw on to the boiling mass, as it 'came to nature,' a small quantity, from 4 to 6 ounces, of saltpetre: this, chiefly by the sudden increase of heat, enabled the puddler to ball his 'heat' more rapidly; and from the same cause, as well as that the cinder was made more liquid, the balls shingled and rolled well. Beyond this there was no difference in the treatment of the 'puddled bars' thus obtained and those made in the ordinary way, these being cut up, piled, heated in the mill-furnace, and rolled into merchantable bars and bolts. The hæmatite used was the Ulverstone ore, and also that to be met with abundantly in the neighbourhood of Workington. The pig-iron was for the most part Scotch, together with a small proportion of hæmatite-pig and white or cinder pig-iron.

"The bar-iron produced was tolerably uniform and of fair quality, fetching at Liverpool and Carlisle about the same prices as the better brands of Welsh bar-iron. Upwards of 1000 tons of bar-iron were made by the above process at Workington, but at a very heavy loss. It is difficult to come to any just conclusion as to how much, if any, of this loss is due to the method of working, seeing that the forge was only open for about nine months, and that all the incidental and unremunerative charges consequent upon the commencing and the closing of any works of magnitude, the expenses of preliminary trials, the loss occasioned by a strike of the puddlers, and a large per centage of bad debts, are all comprised in this loss; moreover the coal in the neighbourhood of Workington was not bituminous enough for iron making, so that the waste in the mill-furnaces, where the puddled bars were converted into merchantable iron, was much above the average. It is true that this waste was much diminished before the works were closed by introducing a jet of tar to the mill furnaces whilst the piles of puddled bars were heating for the final rolling; yet, making every fair allowance for the above and other minor and obviously preventible sources of loss which need not to be incurred in continuous working, it is most likely that the same causes which militated against the success of the processes for obtaining iron direct from the ore alone render this conjoint method also the reverse of economical; since the time, labour, and fuel required to make a ton of puddled bars by this process, are unquestionably greater than where pig-iron alone is used in the puddling furnace, and this to an extent which, probably, more than counter-balances the saving effected in pig-iron. At Workington, even when the forge was in good working order, it was seldom that more than ten heats or charges of iron and ore were puddled in one furnace during the twenty-four hours; and as fuel, wages, and all other charges incurred were the same on these ten heats as if the usual number had been worked in each furnace, it is very doubtful whether these extra expenses were

covered by the saving in pig-iron and the greater weight in yield. This greater weight of yield is the most satisfactory result the books of the forge disclose; for whereas, at the beginning of working, 1 ton of pig-iron and 5 cwts. of hæmatite yielded but from 16 to 17 cwts. of puddled bars, before the works were closed the average yield amounted to nearly 1 ton of puddled bars from 1 ton of pig-iron and 5 cwts. of ore, while some of the best of the puddlers frequently produced a greater weight of puddled bars, than that used of pig-iron. Judging the process as a whole, it is most probable that an opinion adverse to this mode of making bar-iron is the only sound one to be arrived at; seeing that, in addition to the above, the process was partially adopted and employed in some other forges than that at Workington, and yet it is believed, although the patent-right has long expired, that the process now has been abandoned where it was employed, and that it has nowhere been brought to bear, although it might be used unquestioned in any forge in the kingdom."

Actual yields and cost of production.—The forge and mill at Workington were in operation from Octr. 4th, 1845, to July 15th, 1846—a period of rather more than 40 weeks, during which time there were made 1019 tons, 8 cwts., 1 qr. of finished bar-iron.

The materials used were:

	Tons.	cwts.	qrs.	lbs.
Pig-iron and cast-scrap	1175	16	2	0
Burnt iron and old retorts	31	0	0	0
Red hæmatite ore for mixture	252	13	2	0
Ditto do. do. for mending furnaces	381	0	0	0
Coal and slack	3673	0	0	0
Wrought scrap-iron, including "drop-ends"	236	17	0	17

The yield was 1276 tons, 14 cwts., 3 qrs., 23 lbs. of puddled and scrap bars, being an average of 25 cwts. of puddled bars to make 1 ton of merchantable bar-iron. The gross cost of this iron, including all losses, was 12*l.* 5*s.* 3*d.* per ton; whilst the net cost, deducting bad debts, &c., will be 11*l.* 1*s.* 6*d.* per ton of finished bars, the average selling price of which was 9*l.* 1*s.* 10*d.* per ton.

From the above we find that to make 1 ton of finished bar-iron there was used on the average:

Tons.	cwts.	qrs.	lbs.			£.	s.	d.			£.	s.	d.
1	3	2	20	of pig-iron	at	3	15	4	per ton	=	4	9	2
0	3	3	6	of scrap-iron	at	4	8	0	,,	=	0	16	8¾
0	12	1	20	of red ore	at	0	16	3	,,	=	0	10	1¼
3	10	0	0	of coal	at	0	7	10½	,,	=	1	7	6¾

		£.	s.	d.
Cost of materials		7	3	6¾
Wages	per ton	1	17	0
Rent (actual working time)	,,	0	7	1½
Salaries	,,	0	3	4½
Patent licence	,,	0	2	5¾
Constant and incidental charges	,,	1	7	11½
Net cost per ton at market of merchant bar-iron		£11	1	6

The estimate of the actual cost of the same process carried out at a forge in Lancashire, where it was used at a few furnaces only, from details furnished by the forge-masters, calculated on the above prices for materials, is:

Tons.	cwts.	qrs.	lbs.			£.	s.	d.			£.	s.	d.
1	5	1	0	of pig-iron	at	3	15	4	per ton	......	4	15	1½
0	7	2	5	of red ore	at	0	16	3	,,	......	0	6	1½
0	1	2	0	of coke	at	1	5	0	,,	......	0	1	10½
2	14	2	0	of coal	at	0	7	10½	,,	......	1	1	6¼

	£.	s.	d.
Cost of materials	6	4	7¾
Wages	1	7	3
Patent licence	0	3	0
Rent, salaries, constant and incidental charges	0	18	4¼
Cost of 1 ton finished bar-iron	8	13	3
Freight and charges	0	6	0
Net cost per ton of finished bar-iron at market	£8	19	3

Renton's Process.

This process was patented in 1851 in the United States by Mr. James Renton, and has been described by Professor Wilson in a Report to the British Government on the New York Industrial Exhibition.[5] From that Report the following information is extracted. The process was carried out on a commercial scale at Cincinnati in Ohio, and at Newark in New Jersey. Professor Wilson visited the works in both localities. At the former the furnaces were in process of construction, and at the latter they were in full operation. The furnace in shape resembled an ordinary puddling furnace, having a fire brick chamber at the end 10 feet high, 6 feet broad, and 7 inches wide. This chamber, which was, in fact, a large vertical muffle or retort, was entirely surrounded externally by the flue or chimney of the furnace. It was filled with 12 cwts. of a carefully made mixture of from 20 % to 25 % of ore and of from 75 % to 80 % of coal, both finely broken; and became sufficiently heated to cause the reduction of the ore. The reduced ore was discharged, as required, from the bottom of the chamber into the body of the furnace, where it was exposed to a welding heat and worked into balls, which were hammered in the usual way into blooms. At the time of Professor Wilson's visit, hæmatite containing about 35 % of iron was employed, and the balls weighed about 80 lbs. each, i.e., about the same as ordinary puddled balls. It was, however, stated that the average yield amounted to 45 %, and the weight of the balls to 100 lbs. The cost of a ton of blooms was given as follows:

	$ c.
2½ tons[6] of ore at $4	10·00
1½ do. of coal for furnace	6·88
Coal for reduction chamber	1·25
Do. for engine	2·00
Welding and working	5·00
Tilting [shingling ?] $1·5; labour $3	4·50
	29·63

[5] New York Industrial Exhibition. Special Report of Professor Wilson. Presented to the House of Commons in pursuance of their Address of February 6th, 1854.

[6] Note by Professor Wilson, p. 44. "The ton of *iron* is always the gross ton of 2240 lbs.;—except *blooms* and *puddled bars*, which are bought and sold by the 'Ankouy,' or double gross ton of 2464 lbs.; and *nails*, which are sold by the net ton of 2000 lbs."

Professor Wilson remarks, "without criticising these figures, which, perhaps, were given as referring to the most favourable conditions of the manufacture, and which, of course, will vary with different circumstances, I think that we must admit that Mr. Renton has done much in carrying into commercial operation a process which practically does make wrought-iron directly from the ore. The operation was comparatively upon an insignificant scale, it is true, and the quantity made certainly was but small; yet, if the principle is correct, both as regards produce and cost, the capacity of the furnaces could probably be increased, and, at all events, they could be multiplied to any extent. The principal obstacle appeared to me to exist in the difficulty of balling the iron in the welding furnace without getting some imperfectly decomposed ore mixed up with it, which necessitated extra labour with the hammer."

Professor Wilson alludes to another establishment of some magnitude, which was then being erected at Motthaven, near New York, for carrying out Harvey's patented process of reduction, which is similar in principle to Renton's. Magnetic oxide of iron is mixed with charcoal, both in coarse powder; and the mixture is placed on inclined shelves or trays of steatite in a chamber connected with a welding or balling furnace. A fire at the base of the chamber heats the mixture sufficiently to induce ignition, and the flame playing over the face of the trays assists the reduction of the ore, which is then transferred to the welding hearth and there balled in the usual manner. Four furnaces were in process of erection, each capable of producing 5 tons daily.

Messrs. Cooper and Hewitt, of New York, favoured me with the following notice of Renton's process, dated July 26th, 1855:—"It may be interesting to you to be informed that Renton's process is a failure and has been abandoned in this country, as we always insisted that it would be."

Chenot's Process.

In the first International Exhibition in London, 1851, were displayed what were designated "Éponges métalliques," or metallic sponges, with specimens of iron and steel made from them "without smelting the ore."[7] These sponges consisted of metallic iron obtained by the direct reduction of brown hæmatite by cementation in charcoal. They were chiefly in lumps, which, under the burnisher, acquired the metallic lustre and colour of iron. A French metallurgist expressed to me at the time his belief in the value of Chenot's process, especially with reference to the manufacture of cast-steel; and he even ventured to assert that by its means cast-steel might be produced at 40% below the cost at which it was then made in Sheffield! Chenot figured in the International Exhibition in Paris in 1855, and one of the "Grandes Médailles d'Or" was awarded to him for his invention, which Le Play pronounced to be "the greatest metallurgical discovery of the age."

[7] Official Catalogue, France, No. 119.

There are circumstances connected with this award which have been the subject of severe comment, both in this country and on the Continent, and which I record, although they do not redound to the credit of those concerned. The following extract is from the Official Report of my colleague, Mr. Warington Smyth, to the Board of Trade, on the Mining and Metallurgical Products of the Exhibition in question.[8] "A gold medal was awarded to *M. Adrien Chenot*, of Clichy, 'for his remarkable collection of new and important facts, in an industrial point of view, particularly the rational and economical processes applied to the reduction of iron from its ores, and especially for the direct manufacture of various descriptions of steel.' This award was voted after the Prussian and Austrian jurors and myself had left Paris, the remainder of the jury being persuaded that M. Chenot had now brought his process to the point of being commercially valuable. The late M. Chenot, whose untimely death was the result of an accident [he fell out of a window] after the closing of the Exposition, had for many years devoted himself to this particular branch of metallurgy, and had just arrived at the maturing of his plans on a large scale. . . . . M. Chenot calculated that the production of a good quality of steel, including an ample margin for profits, would cost but 40*l*. per ton. . . . . Arrangements for working it on a large scale were about to be made both in France and England towards the end of 1855." Professor Tunner, of Leoben, one of the Austrian members of the jury above alluded to, has published an energetic protest against the award; and his colleague on the jury, Rittinger, has publicly expressed his approval of this proceeding.[9] The Professor asserts that twice did the whole jury negative the proposal to recommend Chenot as worthy of the highest order of merit of the French Exhibition; yet, the third time, a mere remnant of the jury reversed the two previous solemn decisions of the entire body. According to the proverb, in this instance, it may well be said, "the third time pays for all." But there were singular rumours respecting the supposed instigator of these persevering efforts to honour Chenot, in connection with an attempt to introduce the process into Russia; rumours which, if founded, would justify the inference, that zeal for the welfare of that country was not the sole object. I have dwelt at a seemingly unreasonable length on a subject which might be considered irrelevant. But it is not so. When metallurgical processes are extolled in glowing terms, and recommended as unusually promising investments to capitalists by men in conspicuous positions before the world, it is of the utmost importance that nothing should be done to excite even a suspicion of interested motives.

In the International Exhibition in London, 1862, there were some specimens and a wretched model in illustration of the "procédé Chenot," which indicated failure rather than success, and which indeed were scarcely worthy of notice; and no attempt was made to repeat the experiment of 1855 upon the jury of 1862.

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[8] London, 1857, p. 36.

[9] Oesterreichischen Zeitschrift für Berg-und Hüttenwesen. 1856. No. 52. p. 415.

Four English patents were granted in 1856 in connection with this process;[1] and of some the specifications are in such abominable English as to be unintelligible. I give one sentence in exemplification: "The consequence of this principle is the possibility of immediate calefaction, either by injection of flames into the bulk to be reduced, or sometimes by burning in the bulk the fuel mixed and blended with the oxyd, to reduce which latter case is that which generally takes place, save the possibility of withdrawing the charges, except also the mobility of the apparatus in the upper range of the blast furnace, and other furnaces used for the treatment of lead, tin, &c."[2] It is to be hoped that no English patent agent is responsible for this atrocity in composition.

Chenot has found a warm and elaborate chronicler in M. Ed. Grateau, who has recently published a long paper on the "Manufacture of Cast-Steel by the Chenot Process."[3] In this we are informed that in 1822 M. Adrien Chenot left the École des Mines of Paris, and in 1823 made his first trials of a system, of which he had conceived the idea at the Institution above named. In 1831 he erected a furnace on a large scale for the direct treatment of the ores of iron. From 1831 to 1834 inclusive he made innumerable experiments of every description. In 1846 we find Chenot at Clichy-la-Garenne, and "from this date he entered upon the path which has led him to success." After fresh trials, conducted at Clichy and in the Ariége, from 1852 to his death in 1855, Chenot obtained a series of patents, which, his historian states, led to the establishment of his method of making steel as a regular manufacture. I shall describe this method hereafter, and at present treat only of his process of extracting iron.

According to Grateau, works have been erected for carrying out the Chenot process in the following localities: at Baracaldo, near Bilbao, in Spain, 1852; Clichy-la-Garenne, near Paris, 1855; Couillet, near Charleroi, in Belgium, 1856; Pontcharra (Isère), 1856; and at Hautmont (Nord), in France, 1857. It was further announced by the same author in 1859, that new establishments with the same object were about to be erected in Russia, and that "the manufacture had acquired the truly industrial character of perfected methods (des méthodes arrivées à terme)." In illustration, I present an abridgment of Grateau's account of the process as it was conducted at Hautmont.

Supposing the ore to be sufficiently pure, either naturally or by dressing; if in mass, it is broken into lumps of about 30 cubic centimetres (1·779 cubic inch), but if pulverulent, whether naturally, as is the case with oölitic ores, etc., or otherwise, it is agglutinated by compression, with the addition, in some cases, of reducing matters; for

[1] They have all the same date, A.D. 1856. No. 1587. "A Method of Extracting, Eliminating, Extraneous Substances from Steel Sponges" (sic.)—No. 1588. "Improvements in Sorting Ores, or Separating Metals from each other, and from certain Combinations with other Substances." — No. 1589. "Improvements in Machinery for Compressing Metallic Sponges and other Substances." —No. 1590. "Improvements in Apparatus for the Reduction of Metallic Oxyds" (sic).

[2] Vide No. 1590, p. 2.

[3] Revue Universelle. Paris et Liége. 4e. Livraison. 1859. pp. 1-62.

example, 3 % of resin. Thus prepared, it is mixed with more wood charcoal than suffices to remove the whole of the oxygen from the oxide of iron. In practice, an ore containing 55 % of iron is mixed with 1¼ to 1½ its bulk of charcoal, or by weight 190 parts of charcoal to 1000 of ore. With this the reduction furnace, now to be described, is charged.

The furnace consists of a cubical pedestal of mason-work, surmounted by a truncated cone, elliptical in section.[4] Two galleries at right angles run through the pedestal, leaving four pillars at the angles, and upon these are arches which support the fire-places. Within are constructed two rectangular vertical chambers or retorts, $2^{m.}$ long (6 ft. 6·74 in.), $0^{m.}$ 50 wide (1 ft. 7·69 in.), and $8^{m.}$ 50 high (28 ft. 0·65 in.). Below the level of the ground at the bottom is a pit to receive the apparatus for discharging. The total height of the entire furnace from the level of the ground is $13^{m.}$ (42 ft. 7·81 in.), and from the bottom of the pit $14^{m.}$ 20 (46 ft. 7·05 in.). The lower part of the retorts widens somewhat downwards, in order to facilitate the descent of the reduced charge. Round each of the retorts is a series of vertical flues, communicating below with the fire-places, and above with a large flue opening into the air. The whole structure is firmly braced with bar-iron. The bricks employed in constructing the retorts are made with a tongue on the upper surface, and a groove on the under one, whereby lateral displacement is prevented.

If the reduced iron were withdrawn while hot, or even warm, it would, on coming in contact with the air, take fire and be again oxidized. In order to prevent this, at the bottom of the retorts is fixed a rectangular case of sheet iron, $0^{m.}$ 002 (0·08 in.) in thickness, and $4^{m.}$ 50 (14 ft. 9·17 in.) in length; it is termed the "refroidissoir," or cooler, and underneath it is another case of cast-iron, perforated on one side with holes in order to allow the passage of the bars of a grate, and having on the opposite side a projection, or groove, to furnish support to the ends of these bars. There are 50 such bars, $0^{m.}$ 018 (0·7 in.) in diameter, and $0^{m.}$ 020 (0·79 in.) apart from each other. The cooler may, when necessary, be surrounded with a second case, through which circulates a current of cold water, in order to promote the cooling of the reduced iron, and so allow more charges to be withdrawn in a given time. Below the cooler, and on a level with the ground, is a waggon running on rails. The bottom of the waggon is moveable, and may be raised or lowered by means of a horizontal lift on a vertical axis. In the operation of discharging, the moveable bottom of the waggon is brought in contact with the bars of the grate, which are then successively drawn out. The bottom is then lowered to its original position, when the reduced iron drops down and fills the waggon.

The total cost of a furnace such as described, including bricks, iron-work, labour, etc., is estimated at 11,500 francs, or about 460*l.*

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[4] The construction of one of the retorts of the Appolt coke oven will give a good notion of Chenot's reduction chamber. Vide Metallurgy, First Part.

The following details relate to a furnace at Hautmont with a single retort, $1^{m.}$ 50 (4 ft. 11·06 in.) long by $0^{m.}$ 50 (1 ft. 7·69 in.) broad. The double retort furnaces were not even completed when Grateau's description was written.

The cost of labour, per shift of 12 hours, is set down as follows: 1 stoker, for two furnaces, 3 fr.; 1 labourer per furnace for filling and discharging, 2 fr.; 1 labourer for carrying the ore, breaking it, etc., 2 fr.; 1 boy for sifting the charges, 1·5 fr.: making a total of 8·5 fr., or 7*s.* 1*d.*

The daily charge of a furnace with one retort is 1500 kil. (about 1½ ton) of calcined iron-ore, and 500 kil. (about ½ ton) of wood charcoal. Reduction is completed at the end of 3 days, when the preceding charge is withdrawn, and the freshly-formed sponge falls into the cooler, where it remains 3 days, and so the operation is repeated. Thus the entire elaboration, reduction, and cooling last 6 days. The yield is 1100 kil. (about 12 cwts.) of sponge, exclusive of 100 kil. (about 2 cwts.) of charcoal in excess in admixture. There is at the same time a consumption of 1300 kil. (about 1 ton 6 cwts.) of coal as fuel.

The ore employed was from Sommorostro, Biscay, in Spain; it consisted of a mixture of sesquioxide and carbonate of protoxide of iron, and contained 55 °/₀ of iron. At the mines it cost 10 fr. the tonne (about 8*s.* 4*d.* the ton), but at Hautmont 45 fr. (about 1*l.* 17*s.* 6*d.*).

The following analysis is given of the Sommorostro ore:—

Sesquioxide of iron	78·70
Oxide of manganese	0·65
Silica	10·01
Alumina	2·36
Lime	0·06
Water	8·22
	100·00

At Baracaldo, according to Grateau, from 16,000 to 18,000 kil. (about 16 or 18 tons) of iron were made daily, of which 10,000 (about 10 tons) were obtained from iron sponge in finery fires or hearths, and the remainder by the mixed puddling of sponge and cast-iron. Mr. Sandberg reports that at Baracaldo iron in 1862 was made in three different ways: 1. Chenot's indirect heating; 2. Puddling charcoal pig; 3. Puddling coke pig. The prices per ton were respectively 20*l.*, 18*l.*, and 16*l.*

The following analysis is given of the ore used in Chenot's process at Baracaldo; it is from Campanil, near Bilbao:—

Sesquioxide of iron	80·60
Protoxide do.	5·42
Oxide of manganese	2·00
Silica	2·00
Alumina	0·40
Lime	trace
Carbonic acid	3·39
Water	6 30
	100·11

When perfectly reduced, the iron sponge has a bright grey colour, is soft, and can be easily cut with a knife in thin slices; it may be ignited by a match, when it continues to burn until wholly oxidized. The imperfectly reduced ore has a black colour, and can neither be cut nor ignited.

It is stated that on the average the specific gravity of well made sponge should not exceed 1·25; but it is necessarily very variable, depending upon the nature of the ore, the temperature of reduction, etc. Under a pressure carried perhaps to 3000 atmospheres the sponge has been reduced to $\frac{1}{4}$ of its original bulk. During the process of compression there is great evolution of heat.

The application of iron sponge to the manufacture of steel will be subsequently examined. Grateau announces that the Bessemer process has been very properly abandoned, and at the same time predicts a bright future for that of Chenot. He thus expresses himself: "The Chenot process, the fruit of 25 years of persevering researches, and resting upon truly industrial principles, presents the happy alliance of science and practice, and will remain an acquisition to Metallurgy, of which it has enlarged the domain, while bestowing upon industry a new method of obtaining ordinary steel of good quality, of which the use becomes every day more extensive." Grateau's statement concerning Bessemer's process is as erroneous as his prophecy will probably be found to be concerning Chenot's.

I have hitherto described what is termed the external or indirect method of heating, and I have now to notice what is termed the internal or direct method of heating.[5] In this method the ore is reduced by a hot current of carbonic oxide, and not by intermixture with solid carbonaceous matter. The furnace consists essentially of a rectangular vertical reduction chamber, with an iron cooler at the bottom, just as in the first furnace; but in other respects there is considerable difference. The chamber is connected with two carbonic oxide generators or gas-furnaces of the usual construction, one on each long side, communicating with the reducing chamber, near the bottom and above the top of the cooler. Charcoal is the fuel employed. Air is blown into the generators at a pressure equal to $\frac{1}{2}$ in. column of mercury, and a gaseous current, rich in carbonic oxide, is thus maintained upwards through the column of ore in the reduction chamber, at the top of which it burns with its characteristic blue flame, except when it is occasionally damped by the aqueous vapour from the ore. Attempts have been made to dry the ore over this flame, and with success. The pressure of the gas should be such that gas may escape in small quantity at the bottom without burning, yet so that it may be lighted by a match; otherwise, air might get access to the reduced iron and re-oxidize it.

M. Tourangin has proposed a modification of the direct or internal

[5] For much of the following and some of the preceding information I am indebted to my friend Mr. Sandberg, of Sweden, who reported on Chenot's process to the Board of Iron Masters at Stockholm, Novr. 1862.

method of heating, which, Mr. Sandberg reports, has been carried out in three localities near Bilbao, and at one in France. The furnace employed is only about 20 ft. high, and no machinery is required in drawing the charges. The cost is stated to be only half that of one of Chenot's direct furnaces, though its principle is exactly the same. There is a vertical quadrangular chamber, square in section, or nearly so, having a gas-generator on each side, etc. The bottom of the furnace is about 2 ft. below the opening, through which the gas from the generator enters; it slopes forwards and downwards towards the front, which is open; this opening is closed, except during the removal of the iron sponge, which is drawn forwards, when it falls into an iron box, and is covered with ashes to protect it from re-oxidation. Above this opening or drawing-hole several moveable iron bars are inserted in order to support the ore, as has been previously described. The bars are taken out and inserted from time to time according to circumstances. The blast must be kept on during the drawing of the sponge, in order to prevent the admission of air into the furnace. About 20 tons of iron sponge may be produced in such a furnace in a week, and may during the same time be worked into blooms in a charcoal hearth with a yield of 50 %.

The charcoal hearth employed for balling the sponge is nearly similar to that employed in making iron for charcoal tin plates in South Wales. During the hammering of the ball, jets of blue flame escape from it in all directions. If a mill be at hand, the blooms may be rolled, without reheating, into bar of about 1¾ in. square in sectional area; they are cut into lengths of 12 in. During the first rolling, the iron is surrounded by blue flame, and appears very soft. The cut pieces may be re-heated in the mill-furnace fired with coal, and rolled into merchant bars of different sizes.

At Baracaldo the Chenot iron was highly esteemed for horse-shoe nails, and on that account commanded a higher price than puddled iron, although, according to Mr. Sandberg, it was certainly not so homogeneous as the latter. The Chenot iron is reputed to be extremely soft and tough, with a fibrous fracture. What is termed a crystalline fracture was only occasionally seen. At a red heat, Mr. Sandberg states, it was exceedingly soft and easy to manage; it did not present any cracks, though carelessly forged.

Mr. Sandberg has given the following as the cost of production of iron by the Chenot process at different establishments which he visited in 1862. The calculations have been made from data communicated to him.

External or indirect method of heating.—At Baracaldo, making about 2000 tons annually (1862). For 1 ton of finished merchant bar-iron are required,—

1·15 of blooms or No. 1 iron.
1·60 of iron sponge.
2·56 of ore free from powder.
3·00 of ore as gotten, and of which the analysis has been previously given.

Fuel.—

Fuel.—1·00 of coal in the last heating.
1·15 of blooms requires in the charcoal hearth 0·86 of charcoal free from powder, and in the reduction furnace 0·64 of charcoal in powder. For 1·60 of sponge 1·75 of coal is consumed in heating the reduction furnace.
Total weight of charcoal 1·50 and of coal 2·75.

Internal or direct method of heating.—At Laramade, making about 600 tons annually. (The results obtained March, 1863.) For 1 ton of merchant bar-iron are required,—

1·10 of blooms or No. 1 iron.
2·20 of iron sponge.
3·19 of ore, free from powder.
3·75 of ore as gotten. This ore is not so rich as that used at Baracaldo.
Fuel.—1·00 of coal in the last heating.
1·10 of blooms requires in the charcoal hearth 0·88 of charcoal.
2·20 of iron sponge requires 0·99 of charcoal in the reduction furnace.
Total charcoal free from powder 1·87 and coal 1.

Cost of modern process in operation in a few places in Sweden, where it is conducted with the greatest skill. For 1 ton of merchant bar-iron are required,—

1·25 of pig-iron.
2·50 of ore, containing 50 % of iron.
Fuel.—1·66 of charcoal in refining (*i.e.* converting into malleable iron in the charcoal hearth) and welding.
1·25 of pig-iron requires 1·00 in the blast furnace.
Total charcoal 2·66.

For the sake of comparison, the following details are given of the cost in Sweden of smelting and making iron in the charcoal hearth, like that in use at the tin plate works in South Wales. For 1 ton of merchant bar-iron are required,—

1·10 of blooms, not welded.
1·25 of pig-iron.
2·50 of ore, containing 50 % of iron.
Fuel.—1·00 of coal in the last heating of the blooms.
1·10 of blooms requires 0·90 of charcoal in refining, *i.e.* converting into malleable iron, etc.
1·25 of pig-iron requires 1·00 of charcoal in the blast furnace.
Total charcoal 1·90 and coal 1·00.

This is about the same consumption of charcoal and coal as in Chenot's direct process, and in Tourangin's modification.

Poor Chenot seems to have had unbounded faith in his invention, and to have regarded it as a great discovery, in ignorance, no doubt, of what had been previously done by Clay and others. I possess the MS. which Chenot communicated to the jury of Class I. in the International Exhibition of 1851; and from this I extract the following summary of the alleged advantages of his process: "The capability of operating upon all sorts of raw material, in all localities, with any workmen, with small capital, and with little machinery, obtaining the best possible products, really answers the economical question better than any statement in figures. . . . . I defy an ironmaster employing the ordinary methods to obtain cast-iron of medium quality at the same cost at which he would be able to produce

iron in the state of blooms of excellent iron or steel by my system. Irrespective of the advantage of cost, I should be able to use any kind of fuel, and in general should require only half the capital." The reader is now invited to compare this glowing announcement of an enthusiastic inventor with the following calm and dispassionate opinion of competent and disinterested men.

In 1856 the following report was drawn up and presented by MM. Combes, Regnault, and Thirria to the French Minister of Public Works on making iron and steel by the processes of Chenot[6]:—

"1. The cast steels made by Chenot's processes at Clichy-la-Garenne, with the ores of Sommorostro, may be considered of good quality and adapted to the same purposes as the good steels from suitable indigenous [*i.e.* French] irons.

"2. Chenot's processes seem applicable with advantage to the making of steel with certain rich ores of French and foreign origin at works in suitable localities.

"3. It is not probable that these processes, in their actual state, should be applied with advantage to the manufacture of iron, except, perhaps, where rich ores of iron might be procured at a low price and labour would be cheap."

It need hardly be observed that the report, bearing the distinguished names above-mentioned, should carry the greatest weight. The following report on the same subject was drawn up by M. Callon, and adopted by the residual section of the jury of Class I. at the International Exhibition in Paris in 1855.[7] The contrast between this and the other report is remarkable.

"We congratulate M. Chenot on the ingenious arrangements by means of which he is enabled,

"1. To collect by his *electro-magnetic sifter* every portion of the metallic sponge from the fragments of charcoal in admixture, when the charges are drawn out of the lower part of the furnace.

"2. To effect the compression of the sponges, and, when necessary, of all sorts of metallic shavings prepared for treatment or for the formation of alloys.

"3. To realize a considerable advantage in many cases, especially in the *fusion of steel*, in rendering the ashes of the coke employed so fusible that the grates are always clean and free from viscous clinkers which, too often, collect upon them, corrode them, and obstruct the draught.

"In conclusion, the jury is of opinion that there is, perhaps, no exhibitor who has presented a more remarkable *ensemble* of new and important facts in an industrial point of view; that if it cannot at present be affirmed that these discoveries or inventions have reached the state of *industrial development on a great scale*, yet the products have at least *this exceptional perfection due to science or to practice*, which justifies the jury in awarding the 'médaille d'honneur' to M. Chenot."

In the direct extraction of malleable iron from the ore, as Chenot

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[6] Revue Universelle, ante cit. p. 20.

[7] Ibid. p. 9.

proposes, at a temperature which merely suffices to reduce oxide of iron to the metallic state, it is obvious that a very large class of ores, such as the argillaceous carbonates, etc., would be excluded. These ores contain a considerable amount of foreign matter in a state of most intimate mixture; and by no process of electro-sifting is it conceivable that the reduced iron could be separated in a satisfactory manner. The foreign matter might certainly be more or less completely removed in the process of working the reduced and compressed sponge at a welding heat in a charcoal fire or reverberatory furnace, not, however, without great loss from the formation of silicate of protoxide of iron, which would necessarily be produced in large quantity; and so far there would be no advantage over the Catalan method. The reduced ore might, as is reported to have been done in Spain, be puddled in admixture with pig-iron, and with the production, probably, of a better quality of iron than could be obtained from the latter alone. Iron directly extracted in the malleable state at a comparatively low temperature from an ore is not so likely to be contaminated with phosphorus, as iron derived from cast-iron produced by smelting the same ore. This has been previously exemplified by an account of the practice in Finland with respect to lake ores.

The qualities required in an iron-ore suitable for Chenot's process are obviously the following:—1. Purity. The presence of silica would necessarily cause much waste in the process of working the sponge into balls; and magnesia cannot be removed without difficulty and increased consumption of fuel in the same operation. Lime and manganese are stated to be the least objectionable foreign matter. 2. It should be loose in structure, so as to facilitate permeation by the chief agent of reduction, carbonic oxide. No ore can be more favourable to this action than brown iron-ore, owing to the expulsion of its water by heat and the consequent porosity induced in every part of the mass. Dense and compact magnetic oxide would be reduced with much greater difficulty. 3. It should not be fusible *per se* at the temperature at which reduction takes place.

The size of the pieces of ore is important. A large lump will require much longer time for reduction than the same mass broken up, owing to the greater extent of surface thereby exposed to permeation by carbonic oxide. On the other hand, this condition, so favourable to reduction, adds to the loss of iron in the balling process, owing to the increased surface exposed to oxidation. Thus, in balling sponge of the size of beans in a charcoal hearth, the waste has been found to be 28 % greater than with sponge of the size of walnuts.

Mr. Sandberg points out one important consideration with reference to Chenot's process, namely, that the massive portion of red and brown hæmatite is often mixed with 15 % or 20 % of the ore in a pulverulent state. This powder must be separated, and cannot be used without having been aggregated into solid pieces by compression. A machine suitable for this purpose, which cost 50*l.*, was stated to be in operation at Hautmont; but in the three establishments visited by Mr. Sandberg, the pulverulent ore was not used.

Mr. Sandberg nowhere observed uniform and complete reduction of the ore; and this seemed to depend rather upon variation in the compactness or closeness of structure of the ore than upon difference of size in the lumps. Pieces of brown hæmatite varying much in this respect may readily be selected from the same locality. It is asserted by Mr. Sandberg that complete reduction of the ore has never been effected in one operation; and it is always necessary to pick out the imperfectly reduced portions and pass them a second time through the reducing chamber. Experience has proved that all the ore may be completely reduced by prolonged exposure to the action of the reducing gas; but then the increased consumption of fuel becomes so large as compared with the additional amount of ore reduced, that it has been found preferable to submit to the evil of incomplete reduction and afterwards assort the sponge.

Yates's Process.

Mr. Yates has favoured me with a pamphlet containing a detailed description of a method which he proposes for the direct extraction of iron in the malleable state from its ores;[8] and has communicated with me personally on the subject. In principle this process is identical with those previously proposed, the reduction of the ore being effected by heating it in admixture with carbonaceous matter; and the apparatus described appears to me to be merely a modification of that of Chenot. But there are these differences between the two methods: while Chenot heats the reduction chamber by furnaces of the ordinary kind with grates, Yates employs exclusively gas-furnaces, in which carbonic oxide is produced in generators; and while Chenot's reduction chamber is rectangular and formed of fire-brick, Yates's consists of a succession of three oval fire-clay retorts, set vertically over each other and united by socket-joints. I subjoin Mr. Yates's own description *in extenso*.

"The reducing and cementing furnace for iron consists of two upright shafts or reducing chambers of fire-clay, from 30 to 35 feet in height, capable of holding 30 to 40 tons of ore, working continuously at the rate of about 1 to 1½ foot per hour, according to the species of ores operated upon or the product required. The shafts are heated externally by gas, generated in four gas-furnaces, one being placed opposite to the longer side of each of the oval chambers. The flame of the ignited gases impinges upon each shaft, about 10 feet from the bottom of it. This portion of the shaft, or that below the inlet for the gases outside of it, is used as a cooling chamber for the reduced ores to remain in a certain time before being withdrawn, for otherwise the reduced metallic iron would re-absorb oxygen, and thereby partly neutralize the effect. The shafts are fitted with air-tight double-acting filling-hoppers at the top, and with air-tight double-acting doors at the

[8] Iron and Steel: on some Points of Economy in their Manufacture. By Frederick Yates. 1860. pp. 23. Vacher and Sons, 29, Parliament Street, London. It is illustrated with excellent engravings.

bottom; these being so constructed that, whilst filling in the materials at the top or extracting the products at the bottom, no air is admitted at either point. Between the two shafts are heating pipes for the air used for the combustion of the gases—heated air being used in order to save fuel and increase the heat if necessary. The air is heated by means of the waste hot products of combustion in their passage from the top of the shafts to the atmosphere. The gas is here created with cold air. The whole of the blast is supplied by a 12-horse power engine, and the pressure of air employed varies from ½ lb. to 1½ lb., according to the sort of fuel used and various other circumstances. The charging and withdrawing of the materials into or from the shafts respectively take place at short intervals, without, however, allowing air to enter them. The ores are filled into the furnace in pieces varying from the size of a small hen's egg to that of a large nut. The carbon is broken somewhat smaller than either of the sizes above given, so as to fill up the interstices and envelope the pieces of ore, as it were. Both the ores and the carbon are intimately mixed together before being filled into the furnace. The quantity of solid carbon required varies with the character of the ores; but the amount of oxygen combined with the iron in the ores is readily ascertained, and the necessary quantity of carbon for reduction and cementation thence easily calculated—a small excess of carbon producing no material effect. In order to produce precisely similar actions and similar agents to those going on and operating inside an ordinary blast-furnace, and to aid in the reduction and cementation of the iron in the ores by maintaining constant and continuous points of contact between it and the carbonaceous elements, and, furthermore, to secure the presence of the cyanogen compounds (indispensable to the production of steel, and probably of iron also), [? J. P.], I introduce to the inside of the shaft a small current of the reducing and cementing gases from the generators, by means of a flue branching off from the main conduit for the gases to the point of combustion, but considerably lower than this. The reduced ore should always be in a dry state when drawn from the furnace, and must on no account ever be heated so far as to become pasty. Such a furnace represents in its actions the middle part, or about 20 feet, of an ordinary blast-furnace, and here the first operation ends. . . . . The apparatus for fusing the reduced ores containing metallic iron should be a large-sized double puddling furnace, with two generators, and fitted with a tap-hole at a convenient height, in order that the slag from the ores may be tapped off. The bottom of the furnace should be as deep from the level of the working door-plate as is consistent with the convenient working of the iron, after it has been fused and freed from slag. . . . With regard to fluxing the ores, no difficulty is experienced; on the contrary, this method offers peculiar advantages in this respect, if the fluxes be judiciously selected and the requisite heat and flame applied. Generally speaking, the nearest approach to a silicate of protoxide of iron should be aimed at in forming the slag: burnt lime, or raw or half-calcined pure iron-ores, in proper proportions, being suitable and cheap materials for the pur-

pose. The reduced metallic iron, together with the proper fluxes, should be thrown into the single puddling furnace, or into the double one, and gradually fused, under constant stirring, with a neutral flame [*i. e.* not containing free oxygen] to the welding point. In about 30 minutes all will be melted and the slag very fluid, when it should be tapped off, leaving, of course, enough on the bottom to cover the iron, which now can be got together, balled, shingled, and rolled into puddle-bars in the usual way. . . . . Each of these reverberatory furnaces requires a 3-horse power blast. The air for combustion is used hot, and is heated by the waste products of combustion passing off from the furnace. There is, after this, still sufficient heat left to create more than enough steam for the 3-horse power. Four single puddling-furnaces, or two double puddling or smelting furnaces, would be sufficient to make all the wrought-iron produced in one reducing-furnace; and the waste heat from them would create steam for their own blast, and that for the reducing-furnace,—in all, 25-horse power. The furnaces and blast-engine requisite to make 100 to 120 tons of wrought-iron per week would cost 2000*l.* As the reduced iron is in a metallic state on being put into the puddling-furnace, as a matter of course, it does not require decarbonizing, whereby one-third of the time, and at least 50 per cent. of the fuel, are saved, compared to that now employed to make a ton of puddled bars."

Mr. Yates enters the following claim for originality: "Up to the present time, no person, to my knowledge, has formed a perfect and entire system, like the present, embracing the manufacture of wrought-iron or steel direct, or cast-iron by a divided process like the present, using gas exclusively as heating, and partly as reducing and cementing agent throughout all the operations from the beginning to the end; nor has any one before, for any purpose, constructed an apparatus on this principle on so large a scale."

A very favourable estimate is given by Mr. Yates of the cost of production of bar-iron by his process as compared with that of the ordinary course of smelting and manufacture. Thus, assuming that 1½ cwt. of coke (168 lbs.) are used to produce 1 cwt. of cast-iron (112 lbs.),—that the 100 lbs. of bituminous coal shall contain 81½ lbs. of carbon, 3½ of hydrogen, 9 of water and nitrogen, and 6 of ashes, etc.,—that the 100 lbs. of coal shall yield 72 lbs. of coke,—the estimated saving on a ton of merchant iron at 8*l.* per ton is 1*l.* 18*s.* 7½*d.* The items are as under:

	£.	s.	d.	
In the reduction process	0	17	0	or 60¾ % saving.
Do. puddling do.	0	8	7½	„ 57½ % „
Do. reheating do.	0	3	0	„ 46 % „
	1	8	7½	
33 % on the waste taken at 22 % for puddling and reheating; or 156 lbs. of iron at 5*s.* per cwt.	0	7	0	
25 % on the time, at 12*s.* per ton, for puddling and reheating	0	3	0	
	1	18	7½	

The reader, especially if experienced in the smelting and manufacture of iron, will hardly require to be cautioned against placing too much reliance on estimates like this, which, although they may be put forth *boná fide* by the inventor, may yet prove fallacious. Mr. Yates remarks, "it is evident [from certain details which he presents] that the present mode of working iron-ores, whether rich or poor, is not the most rational or economic one, although almost the only one in general use. Why convert iron already malleable into cast-iron, to be reconverted, at much labour and cost, into malleable iron again? Why, if the ores were originally pure enough, produce grey cast-iron, when soft or inferior steel may as easily be produced? If cast-iron is to be made, why produce it at such an immense sacrifice of fuel?" These questions are extremely obvious. They have been repeatedly proposed before, but never yet satisfactorily answered; and as some years have now elapsed since Mr. Yates made known his invention, and it still remains in abeyance, it is to be feared that he may not have met with greater success than previous inventors in the same line.

INDIRECT EXTRACTION OF IRON IN THE STATE OF CAST-IRON FROM THE ORE.

After what has been advanced concerning the reduction of the oxides of iron by carbon and carbonic oxide, and the conditions under which the carburization of iron occurs, the chemical phenomena of the modern blast-furnace for the production of cast-iron will be readily intelligible. Much has been written on this subject tending rather to confuse than elucidate it. The furnace being in operation, or, as it is technically termed, in blast, iron-yielding materials (of which the essential part is oxide of iron), flux (generally limestone), and fuel are continually thrown in at the top, so that the interior may be kept filled up nearly to the filling-holes, while slag or "cinder" and cast-iron continually accumulate in the hearth at the bottom, the former flowing out over the dam, and the latter being allowed to escape at intervals through the tapping hole. Thus the solid contents of the furnace are gradually and uninterruptedly descending, and a current of atmospheric air from the twyers is continually ascending to the top, where it either escapes or is carried away to a distance in pipes. The oxygen of the air from the twyers as it impinges on the highly incandescent fuel is in a greater or less degree converted into carbonic acid, which immediately afterwards passes to the state of carbonic oxide. If, therefore, the furnace contained no oxidized substance capable of reduction by carbonic oxide, and no substance volatile at high temperatures *per se* either wholly or partially, the gaseous current would undergo no further change in composition in its progress upwards, and the gas evolved at the top would chiefly consist of nitrogen and carbonic oxide. But this is not the case. Oxide of iron, easily reducible by carbonic oxide, is present; there is also limestone which may be resolved into lime and carbonic acid; and, unless absolutely pure carbon were employed, certain volatile matters would proceed from the fuel. The oxide of iron in its descent is reduced partly by direct contact with incandescent carbon, but chiefly by carbonic oxide in the manner previously described. The temperature of the furnace, it is obvious, must increase in proportion to the depth from the top, and the reduced iron towards the lower and hottest part becomes carburized, and converted into cast-iron, which trickles down in a molten state to the bottom. But the oxide of iron smelted is not pure, being associated with various so-called earthy matters, such as silica, alumina, etc., and the fuel does not consist of pure carbon, but contains also earthy matters or ashes. In order that the reduced iron may be separated, it is essential that the earthy matters from both these sources should be liquefied; and generally their nature is such that liquefaction cannot be effected without the addition of a flux, and for this purpose lime generally answers admirably

in every respect. Moreover, when silica is present, as is usually the case, either free or combined, or in both states, if the iron-yielding materials and the ashes of the fuel did not of themselves contain sufficient earthy bases to form basic silicates, silicate of protoxide of iron might be produced and escape as slag, thus causing considerable loss of iron. Now lime would tend to obviate this evil either by preventing the formation of silicate of protoxide of iron, or, in the event of its formation, by decomposing it and displacing the protoxide of iron. As it is, under certain conditions, especially that of a *heavy* burden, *i. e.* a large proportion of iron-yielding materials and a relatively small proportion of fuel, the evil does arise and is actually tolerated. But this is a point to be reserved for future discussion. The slag may play an important part in protecting the surface of the molten metal in the hearth from possible decarburization under the oxidizing influence of the blast.

DESCRIPTION OF THE BLAST-FURNACE.

Blast-furnace at Corngreaves, Staffordshire.

As a typical illustration of a modern English blast-furnace, in which coke or coal is used as fuel, I have selected one of a pair of similar furnaces, erected in 1861 at the Corngreaves Iron-works, according to the design of my friend, Mr. Kenyon Blackwell, to whom I am indebted for the drawings from which the wood-cuts have been executed. The names of the several parts vary, as might be anticipated, in different parts of Great Britain. The nomenclature employed in the following description is that of South Staffordshire; but in subsequent descriptions of other furnaces I shall state the chief variations peculiar to localities.

The furnace consists essentially of a vertical chamber which I will henceforth designate the shaft; it is circular in horizontal section, but widens from the bottom upwards and from the top downwards, as shown in fig. 29. The shaft is formed of an inner lining of fire-brick called the ring-wall, and an outer casing or shell partly of fire-brick and partly of common brick: see fig. 29, in which the light sectional shading represents fire-brick, and the dark common brick. The furnace is supported on five pillars of brick, which rest on a solid foundation; see figs. 29, 30, *a*, *a*, etc. These pillars, which I will designate simply *the* pillars, are connected above by arches, fig. 29, *b*, *b*, thus making a solid and continuous bed to sustain the superstructure. The lower part of the shaft from *c* downwards, fig. 29, is built after the completion of the upper part of the furnace, and is quite independent of it, so as to admit of being removed and replaced without difficulty. The part of the shaft from about *d* downwards, fig. 29, is termed the hearth; it is flat at the bottom, and opens towards the front or fore-part of the furnace, figs. 29, 30, *e*. At a certain height from the hearth-bottom and on

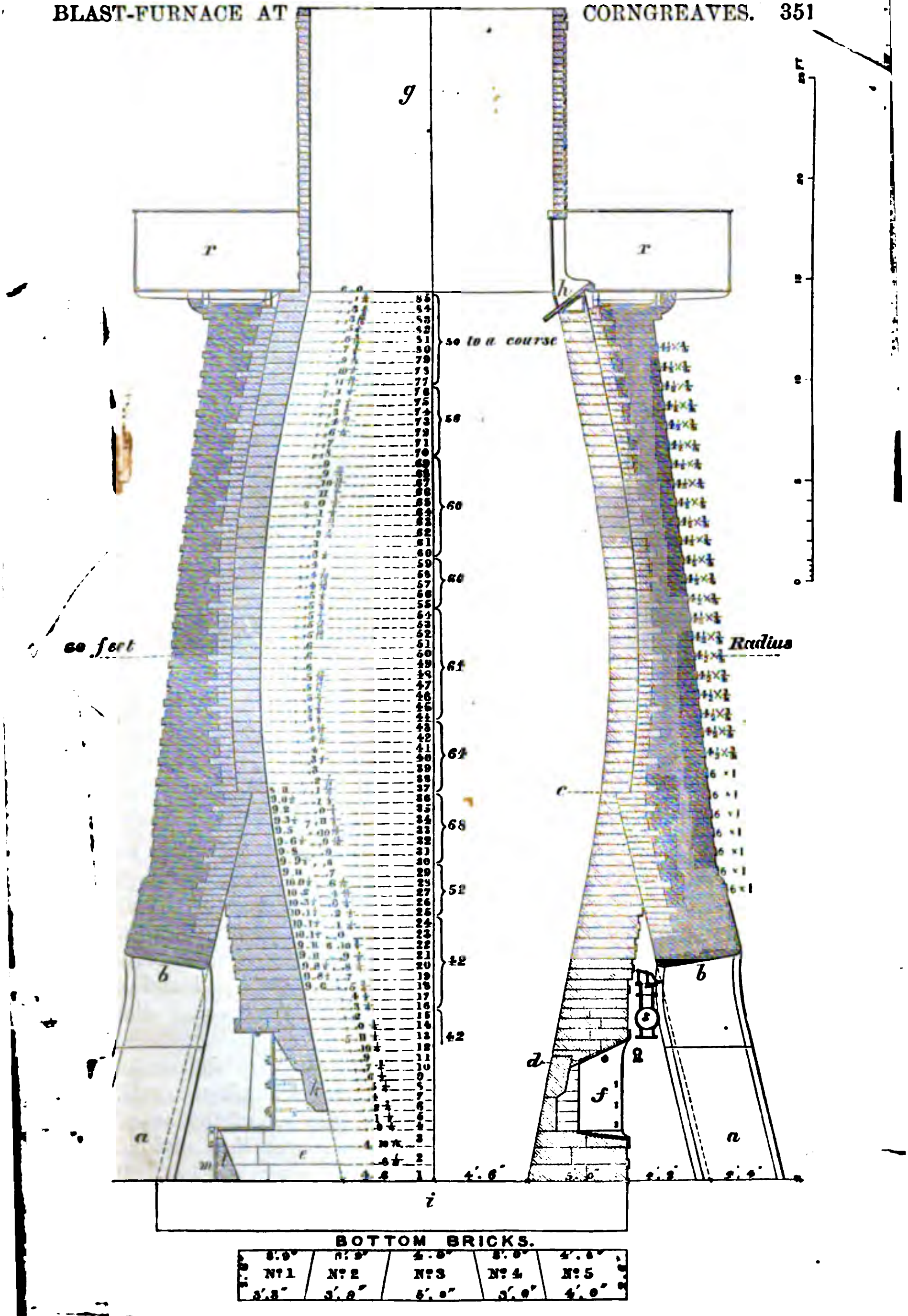


Fig. 29. Blast-furnace at Corngreaves, Staffordshire. Section through front twyer-house and charging door. The numbers on the left from 8 ft. 11 in. to 9 ft. 6 in. are the radii of the external circumference of the bricks forming this part of the furnace. The list ends at 9 ft. 6 in., and below this to the bottom the radius is the same. The whole of the two lists of radii given are intended as memoranda for the brickmaker; the list from top to bottom being internal radii, the other the radii of the external circumference of the bricks. The numbers on the right side externally indicate the width and thickness of the hoops of iron.

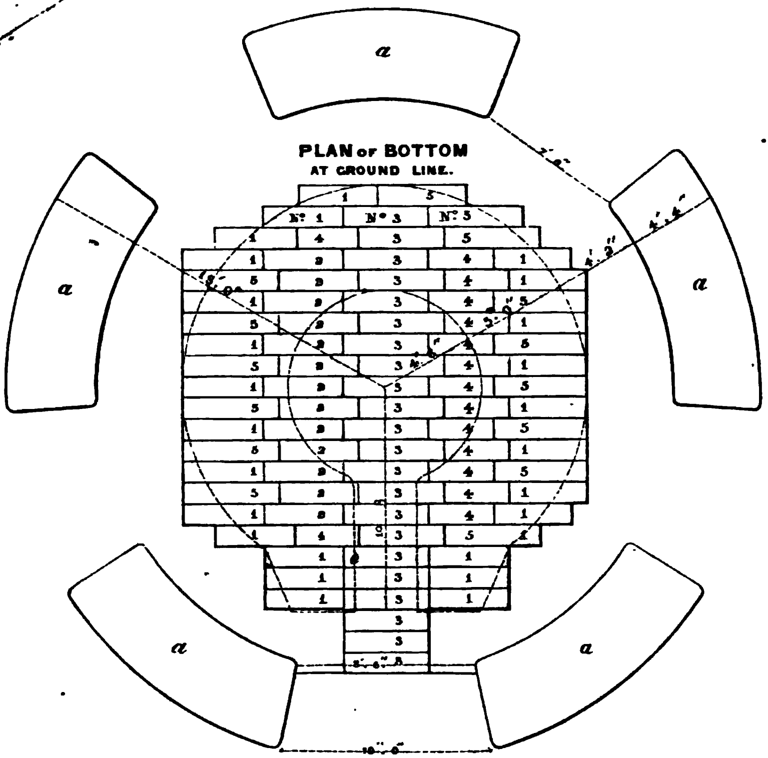


Fig. 30. Blast-furnace at Corngreaves, Staffordshire. Plan.

the same level is a series of four quadrangular openings to receive the twyers: see fig. 29, *f*. The centres of these openings, including that of the opening of the front of the hearth, divide the circumference into five equal parts. The top or mouth of the furnace is surmounted by a cylindrical chimney, termed the tunnel-head, fig. 29, *g*, around the lower part of which are four equal and similar rectangular openings or filling-holes, fig. 29, *h*, at equal distances from each other successively.

In old furnaces the form of the shaft was very different. The mouth was much narrower, there was great widening towards the lower part, and then rapid contraction to the top of the hearth, the sides of which were vertical. The furnace was thus divided into specific zones, the limits of which were exactly marked out. But in some of the most approved modern furnaces such as that in process of description, there are no such definite limits, the curvature being gradual and regular from top to bottom. The lower part extending from the widest part to the top of the hearth was called the boshes, and this term is still retained, though it is difficult in some cases to point out where they begin or end. They may, however, be recognised as the removable lower portion of the shaft above the hearth, and

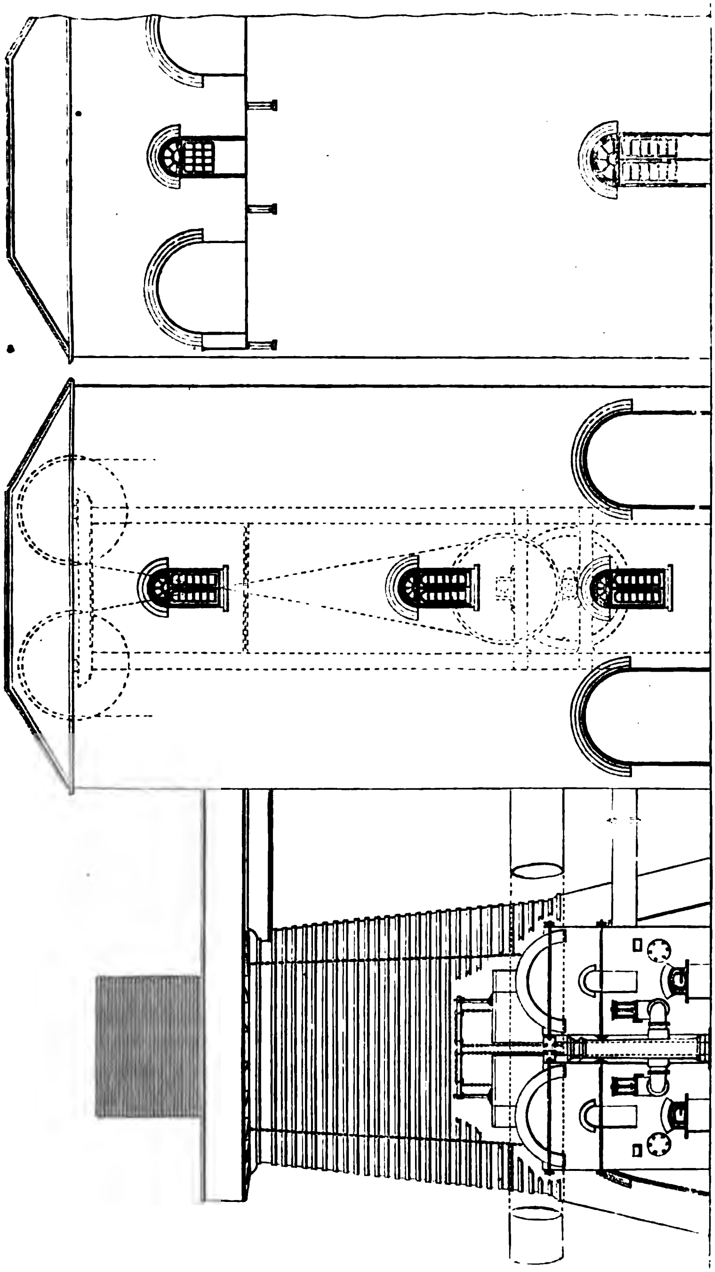


Fig. 31. Blast-furnace at Corngreaves, Staffordshire. Back Elevation. Front of Lift.

they will be more clearly indicated in engravings of other furnaces to be subsequently introduced.

Foundation.—Owing to the defective nature of the ground, the foundation was commenced 15 feet below the surface by a bed of concrete, 3 feet 6 inches thick, formed of broken up blast-furnace cinder grouted with lime mortar. On this bed rest the five pillars which carry the shell and lining of the furnace. After the completion of the entire superstructure, the hearth was put in as follows: the whole space within the pillars was filled up with offal fire-bricks grouted with fire-clay to within 5 feet of the hearth bottom, and upon the second bed thus formed was laid a course of Gornal sandstone, 2 feet 6 inches thick, surrounded by offal fire-brick; on this second bed was laid a third of large dove-tailed fire-bricks, also 2 feet 6 inches in depth: see figs. 29 *i*, 30. The foundation below this course of bricks is not shown in the engravings. It will be perceived that, owing to the shape and mode of adjusting these bricks, they cannot be forced up by any molten metal which may find its way underneath.

Hearth.—The sides of the opening at the fore-part are vertical to a certain height from the bottom and then slope outwards. At the top it is covered in by an arch, termed the tymp-arch, figs. 29, 32, *k*.

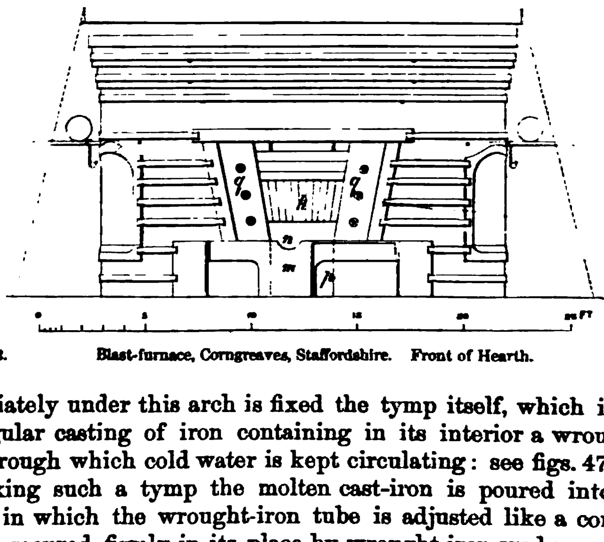


Fig. 32. Blast-furnace, Corngreaves, Staffordshire. Front of Hearth.

Immediately under this arch is fixed the tymp itself, which is a long rectangular casting of iron containing in its interior a wrought-iron tube through which cold water is kept circulating: see figs. 47, 48, 49.[1] In making such a tymp the molten cast-iron is poured into a sand-mould, in which the wrought-iron tube is adjusted like a core. The tymp is secured firmly in its place by wrought-iron wedges. In front the hearth is prolonged outwards, as shown in figs. 29, 35, *e*; it is closed in this direction by a wall of fire-brick, called the dam, fig. 29, *l*, of which the inner surface inclines outwards, while the outer one is vertical and firmly supported by a strong cast-iron plate, called the dam-plate, figs. 29, 32, *m*. At the upper edge of this plate is a notch, *n*, called the cinder-notch, over which the

[1] This engraving of a water-tymp belongs to the furnace next in order of description.

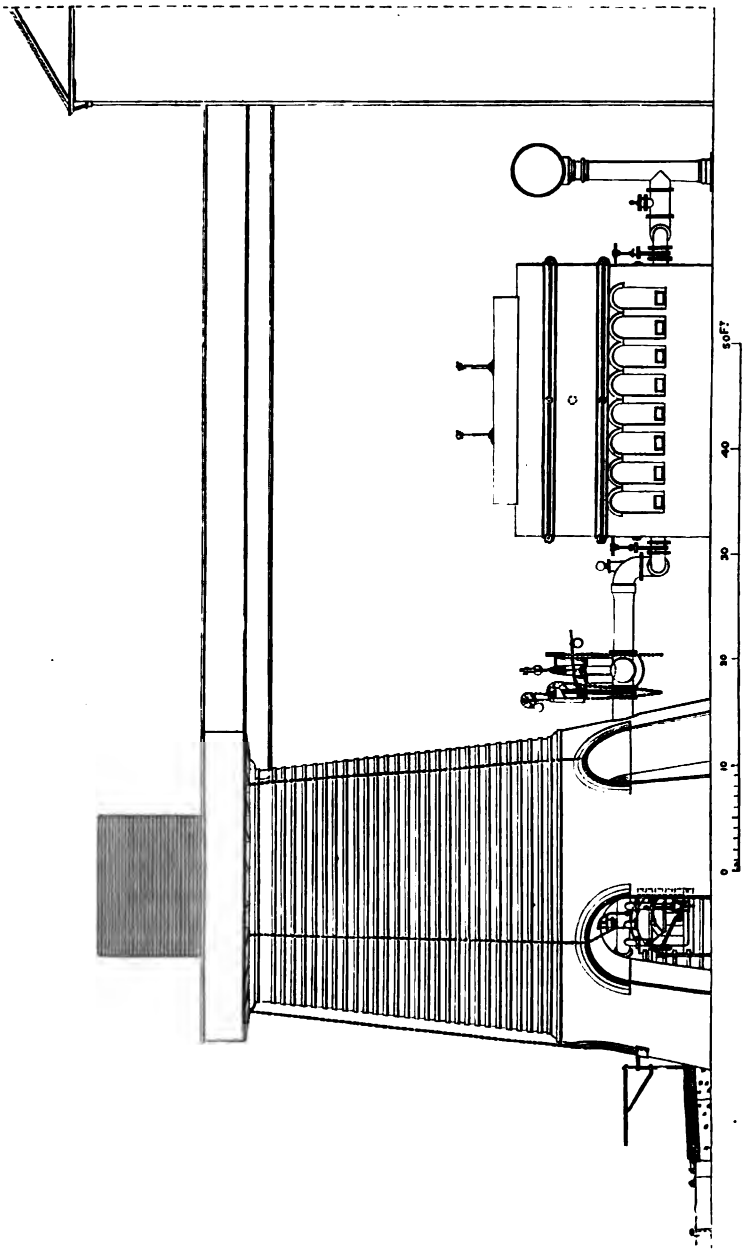


Fig. 33

Blast-furnace, Corngreaves, Staffordshire. Side Elevation.

stream of molten slag flows down the inclined plane leading therefrom, called the cinder-fall: see fig. 33. At the bottom of the dam, and, in the furnace now being described, on the right-hand of the dam-plate, is a channel, the tapping-hole, communicating with the interior of the hearth, and through which the metal is tapped out, figs. 32, 35, *p*. During the working of the furnace it is stopped by ramming in sand. In some furnaces a notch in the bottom of the dam-plate itself forms the mouth of the tapping-hole. But this arrangement is strongly objected to by some furnace managers, because if the furnace "works cold," or is stopped from any accident, it would be necessary to cut the tapping-hole upwards, which could not be done under the circumstances. The space between the top of the dam and the tymp is stopped either with sand or clay, more or less completely, care being subsequently taken to form a channel for the escape of the slag when it has accumulated in the hearth to a sufficient height to overflow. On each side of the opening at the fore-part strong plates of cast-iron are fixed, fig. 32, *q*, *q*. The lower part of the hearth within the pillars is well braced with bars of iron dovetailed into the large castings which form the twyer-openings, fig. 32.

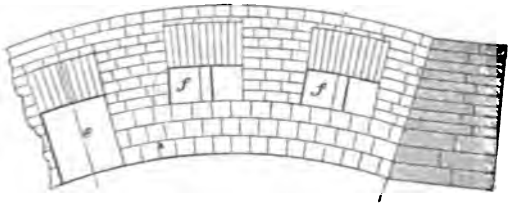


Fig. 34. Blast-furnace, Corngreaves, Staffordshire. Development of half of twelve courses.

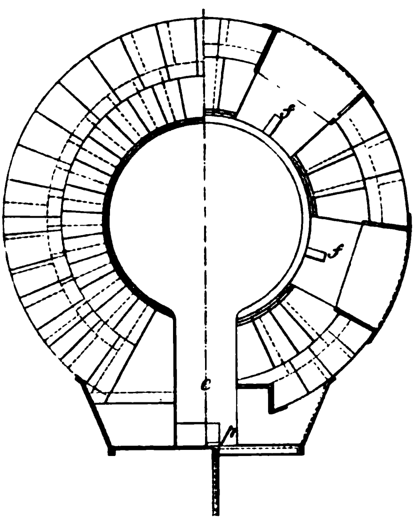


Fig. 35. Blast-furnace, Corngreaves, Staffordshire. Plan of first and second courses shown on the left, and of the fourth and fifth courses on the right of the vertical median line.

Twyer-openings.—They are divided towards the interior in the middle by a pier of bricks, figs. 34, 35, *f*, *f*, thus forming two equal apertures, called twyer-holes, in each of which is a twyer; and towards the exterior they are enlarged and cased on all sides by the large castings into which the bars above mentioned are dovetailed. It will be observed that the air circulates freely round the outside of the hearth, which is thereby prevented from becoming too hot and rapidly destroyed in consequence. The furnace men can thus obtain ready access to the twyers and perform with

the least discomfort to themselves any work which may be required in connection therewith. This is an important consideration; for in the old furnaces one had to grope to the twyers through dark, narrow, tortuous, and hot passages, pretty much as Belzoni did when he forced his way into the interior of the Egyptian Pyramid. Obviously, conditions like these are not favourable to the satisfactory execution of any kind of work. Moderate attention, at least, to the comfort of workmen is not bad policy, any more than it is for a doctor to make physic palatable when he really wishes the patient to swallow it. This is somewhat common-place philosophy, but it is too often neglected, even in Iron-works.

Twyer.—This is a hollow truncated cone of wrought-iron, of which the sides are hollow to allow of the circulation of cold water through them, as shown in fig. 44. In the axis lies the nose of the blast-pipe, which is also of wrought-iron. When a twyer leaks from being burnt or otherwise, it can easily be repaired. Twyers are usually made sufficiently long to allow of such reparation several times without being rendered too short to be unserviceable. They are placed with their axes horizontal and towards the centre of the furnace in a greater or less degree, according to circumstances. The open space of the twyer-holes surrounding them is stopped with tempered shale or sand. Other kinds of twyer will be subsequently described.

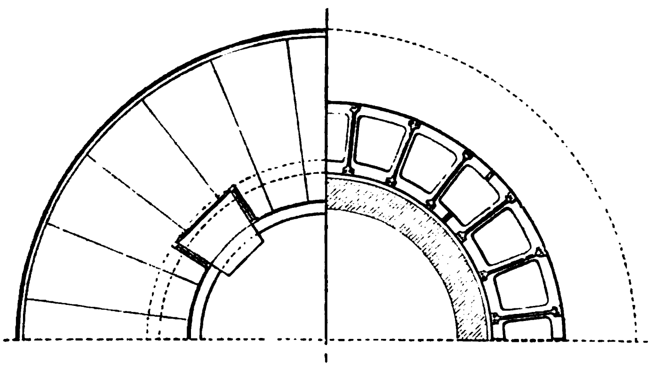


Fig. 36. Blast-furnace, Corngreaves, Staffordshire. Plan of the gallery at the top shown on the left, and section of furnace-lining at level of bottom of wall-plate shown on the right of the vertical median line.

Tunnel-head.—Each filling-hole is protected by iron castings forming a hopper, of which the bottom plate projects and slopes downwards into the furnace. The brick shaft forming the tunnel-head is hooped with iron. Extending round the mouth of the furnace is a gallery, the floor of which consists of plates of cast-iron united by flanges underneath, figs. 29 *r*, *r*, 36. This gallery communicates by a bridge with a vertical lift by which the materials for charging the furnace are raised: see figs. 31 and 33.

Bracing.—This furnace is braced with hoops of iron, which rest on the projecting ends of bricks left purposely at intervals. There is, probably, no better method of bracing than this, whether in reference

to strength or economy. An entire external casing of boiler-plate has been employed in several localities, as will be seen hereafter. But it is very costly, as compared with hooping, and some practical smelters, who have tried both systems, have decided in favour of hoops. Such a casing is objectionable, not only because it can with difficulty be repaired in the event of its bursting from the expansion of the furnace, but also because it renders it difficult to effect any repairs which may become necessary in the internal brickwork. If hoops are employed, it is well to suspend chains vertically from the top to the bottom of the furnace in order to prevent any hoop, which may suddenly break, as sometimes happens, from springing off and then falling on persons underneath. Fatal accidents have been occasioned in this manner. See figs. 31 and 33.

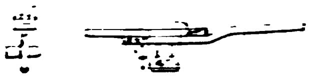


Fig. 3[illegible]. Mode of fastening the Hoops.

Blast-main.—The blast-main of this furnace consists of cast-iron pipes united by socket-joints. It passes round the furnace within the pillars, above the twyer openings, and is supported on brackets, figs. 31, 33. It conveys the hot-blast to the blast-pipes, one of which passes to each twyer. The object of this arrangement, whereby the blast is conducted downwards to the twyers, is to render the pipes everywhere accessible, and to prevent the return of cinder into the main from the twyers when the pressure of the blast is suddenly removed.

Blast-pipes.—These are tapering retort or goose-necked pipes, partly of cast and partly of wrought-iron, by which the blast is conveyed to the twyers. When cold-blast is employed, the blast-pipes may be connected with the blast-main by leather pipes, and are generally inserted loosely in the twyers. With hot-blast, on the contrary, the joints and apparatus for adjustment and regulation are wholly of iron. At the elbow is a small opening in the prolongation of the axis of the twyer closed by a moveable valve or plug of cast-iron, fig. 33. By removing the latter a current of blast escapes and may be directed on a piece of lead, for example, in order approximately to ascertain its temperature; and, moreover, to inspect the interior of the twyer, or remove any obstruction from its nose by means of a pricker-bar. See also fig. 40.

Special Observations.—This furnace is composed partly of fire-brick and partly of common-brick; but Mr. Kenyon Blackwell recommends that fire-brick should be exclusively used. In the outer casing of brickwork small radial spaces are left at intervals to allow for expansion; but there are no such spaces in the inner fire-brick lining. Formerly, an annular space was always left between the lining and the shell, which was afterwards filled with sand, or some other refractory and badly conducting material; and this practice is still occasionally continued. The old furnaces were usually pyramidal in form and very much more massive than the modern, of which some have been reduced to the extreme of attenuation, resembling columns rather than pyramids.

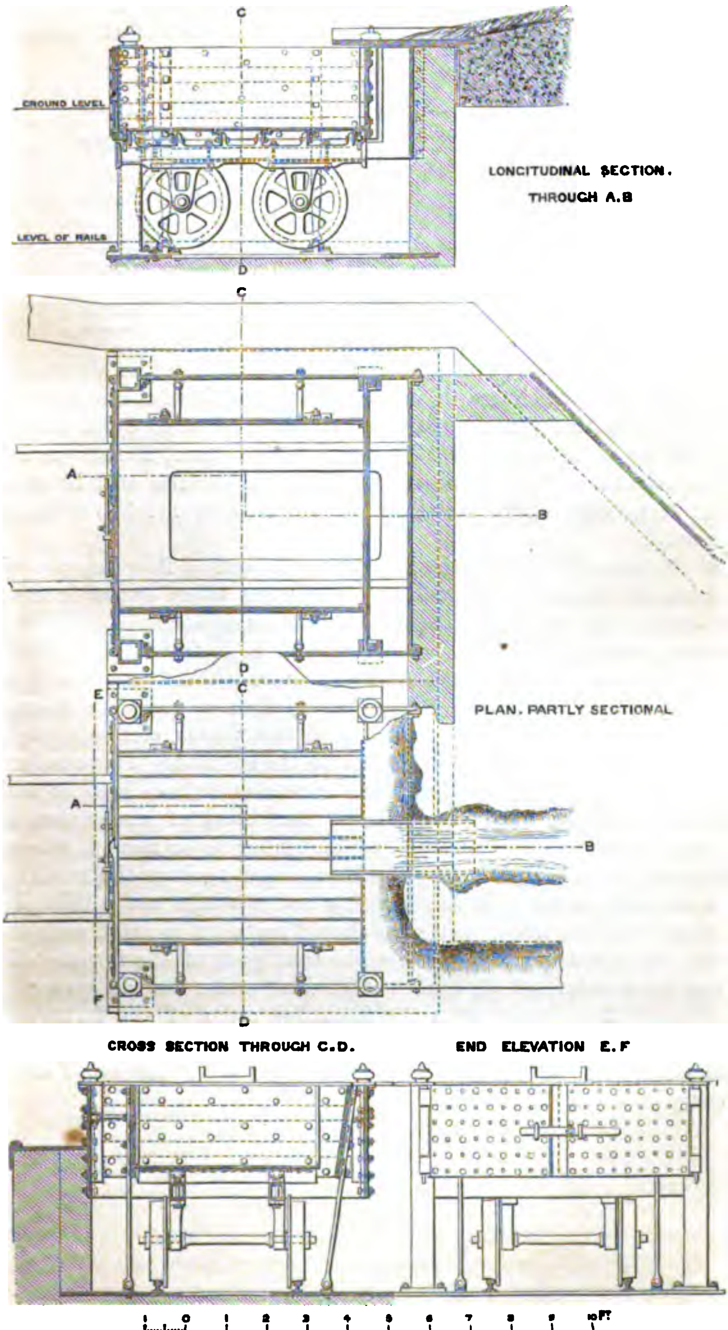


Fig. 38. Cinder-tub, Corngreaves, Staffordshire.

Mr. Kenyon Blackwell has furnished the following details of the cost of construction of two of these furnaces, inclusive of all necessary appliances :—

Furnaces, £1000 each	£2000
Hot-air ovens, containing 60 pipes to each blast-fire, in 2 sets of 30 pipes, £500	1000
Steam lift 24 in. high pressure engines, 3 ft. stroke ; drum, pulleys, wire ropes, carriages, brick house, and bridge	1000
Blast, steam, and water pipes	500
Railroads, pig beds, loose stock	1500
	£6000

Blast-engines.—There are two engines not coupled at each extremity of blast-mains (which are of wrought-iron, 5 ft. in diameter, acting as regulators), with 52-inch steam, and 100-inch blowing cylinders, 8 ft. 6 in. stroke, each with heavy fly-wheels. The steam, 20 lbs. per inch, is used expansively and condensed. The two engines will blow five or six furnaces. There are six at the Works, at from 3¾ to 4 lb. inch pressure.

Cinder-tubs.—Formerly the cinder was allowed to flow into a cavity in front of the cinder-fall, from which it was taken out at intervals (see description, p. 361). The convenient arrangement of cinder-tubs is now generally adopted. One of these tubs is fully represented in fig. 38. It consists of a truck of iron, around which four sides of iron are adjusted at the cinder-fall, so as to form a complete waggon. These sides, which consist of perforated iron plates, can be easily let down or put up, in the manner shown in the engraving above referred to. When the waggon is filled, the cinder will have become solid, and the sides may then be detached. The block of cinder thus left exposed on the truck is conveyed to the cinder tip or mound, where it is thrown away. Occasionally the horse used to draw the truck has been severely burnt from the bursting out of cinder not solidified in the interior of the mass ; and care should be taken to avoid such accidents. It is now possible to keep the front part of the furnace clear and in good order, which could not be done under the old system. I was remarkably struck with the beautiful order of the furnaces at Cyfartha, where the cinder is removed in tubs. I tried in vain for some time to procure, near the furnaces, a small specimen of cinder to carry off as an illustration.

BLAST-FURNACE, RUSSELL'S HALL, NEAR DUDLEY, SOUTH STAFFORDSHIRE.

This furnace differs considerably both in form and construction from that at Corngreaves. It was designed and erected by my friend, Mr. S. H. Blackwell, after the model first adopted at Dundyvan, in Scotland. The woodcuts have been executed from beautiful drawings prepared expressly by my friend, Mr. George Shaw, of Birmingham. After the detailed description which has been given of the component parts of a blast-furnace, it will suffice to point out the distinctive characters of the furnace now under consideration.

When blast-furnaces are built slightly of brick only, and hooped or cased with iron, they are usually designated *cupola furnaces*, to distinguish them from massive furnaces like those of Corngreaves.

The shaft is nearly cylindrical from the mouth to the commencement of the boshes, indicated by the transverse line below the dotted line A B, fig. 40. From this line it gradually contracts to the bottom of the boshes, when it becomes cylindrical at the upper part of the hearth; it then again contracts for a very short distance, after which the diameter remains the same to the bottom of the hearth. The exterior of the furnace is cylindrical from the mouth downwards. The hearth-bottom is formed of large blocks of sandstone. There are five twyers: see fig. 42. The superstructure of the furnace is supported on cast-iron standards, and entirely cased with boiler-plate up to the mouth: see figs. 39, 40; enlarged representations of the standards are given in fig. 46. They rest on a cast-iron ring, 19 ft. 6 in. in internal diameter, 1 ft. 6 in. wide, and 4 in. thick. The lining and shell are separated by an annular space filled with sand. There are five filling-holes. In fig. 40 the cast-iron plates projecting from these holes downwards into the furnace are shown supported on bosses of brickwork. There were, however, in reality no such bosses; but they have been introduced by the advice of Mr. Blackwell, who recommends their adoption in order to prevent as much as possible the warping of the plates.

The construction of the fore-part will be intelligible from figs. 39, 45. In fig. 39 it is shown without the dam. There is a second arch above the tymp-arch. The crane is employed for raising the large cake of slag which accumulates in what is termed the roughing-hole. In fig. 45 the dam is shown with the water-tymp *in situ*. The space between the upper surface of the tymp and the tymp-arch is bricked up. The tapping-hole is in the dam-plate. There are at intervals round the furnace vertical cast-iron bars, figs. 39, 40, 45, which are notched, as shown, in order to furnish support for crowbars to be used as levers.

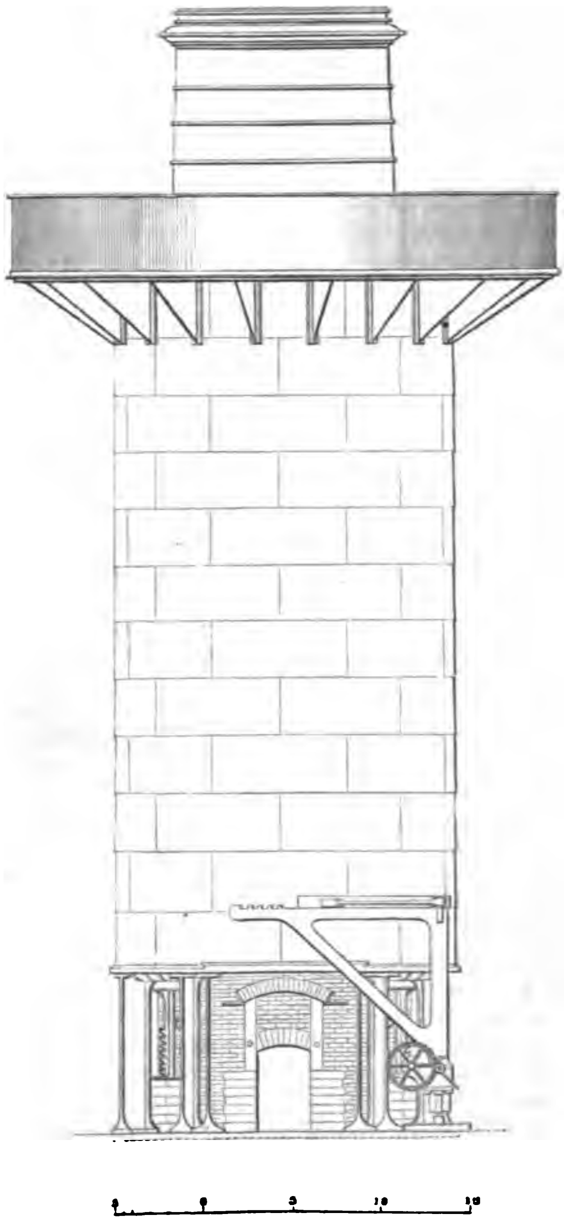


Fig. 39. Blast-furnace, Russell's Hall, near Dudley, Staffordshire. Front elevation, as the furnace is seen without the dam before blowing in.

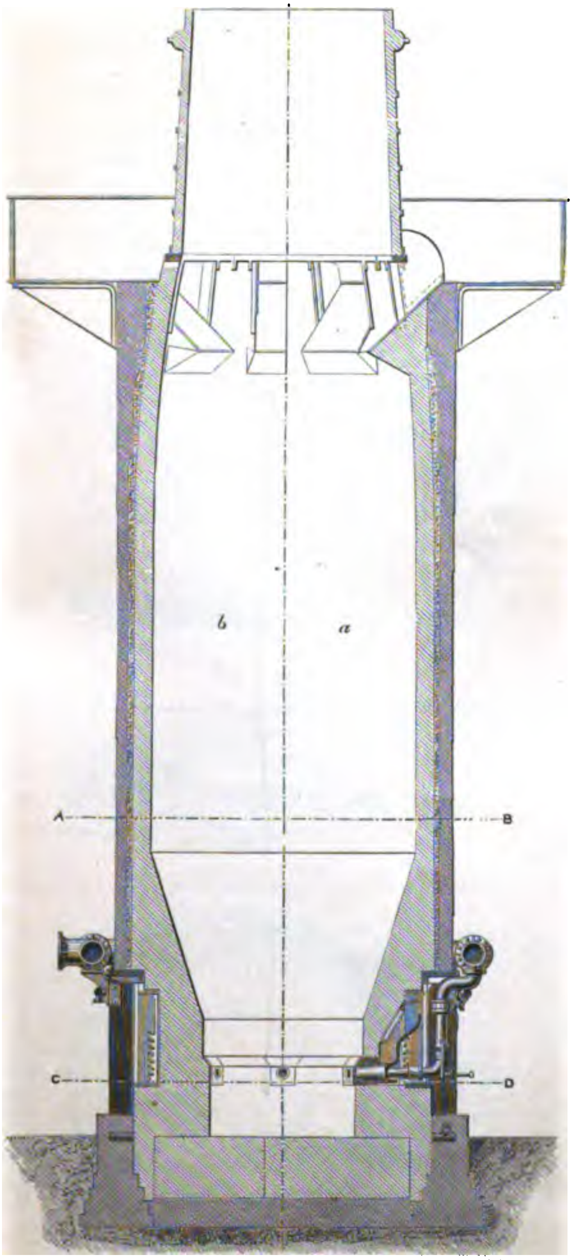


Fig. 40. Blast-furnace, Russell's Hall, near Dudley, Staffordshire. Vertical (double) section. The side a is through the line a^1, fig. 42, and the side b through the line b^2, fig. 42.

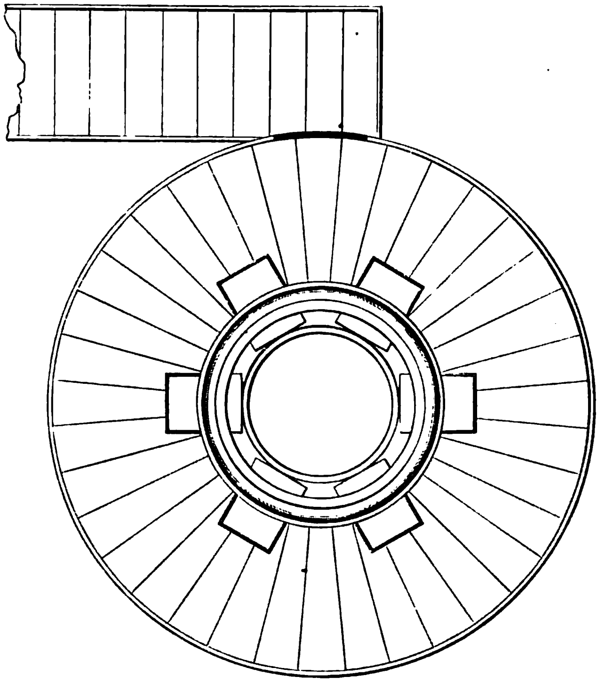


Fig. 41. Blast-furnace, Russell's Hall, near Dudley, Staffordshire. Plan of the furnace at the top.

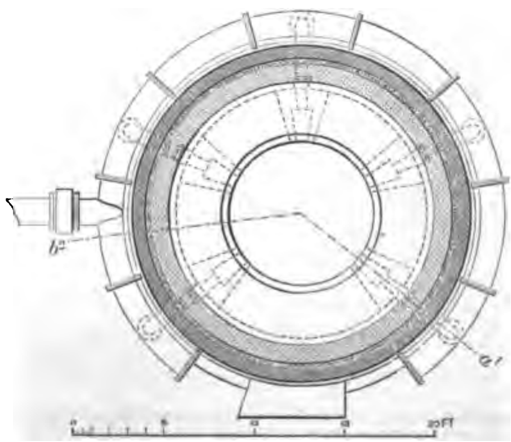


Fig. 42. Blast-furnace, Russell's Hall, near Dudley, Staffordshire.

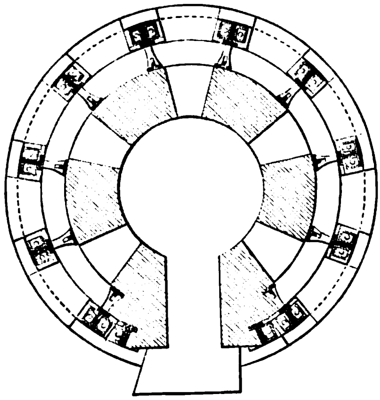


Fig. 43. Blast-furnace, Russell's Hall, near Dudley, Staffordshire. Horizontal section at the twyers.

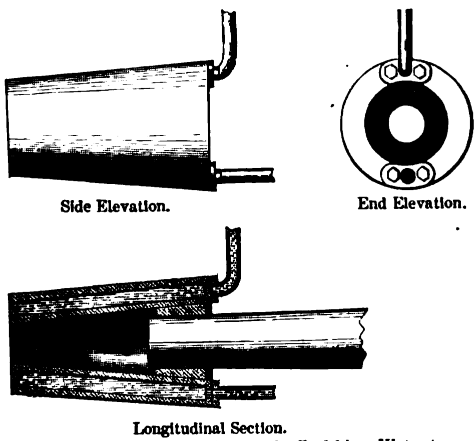


Fig. 44. Blast-furnace, Russell's Hall, near Dudley, Staffordshire. Water twyer of wrought-iron.

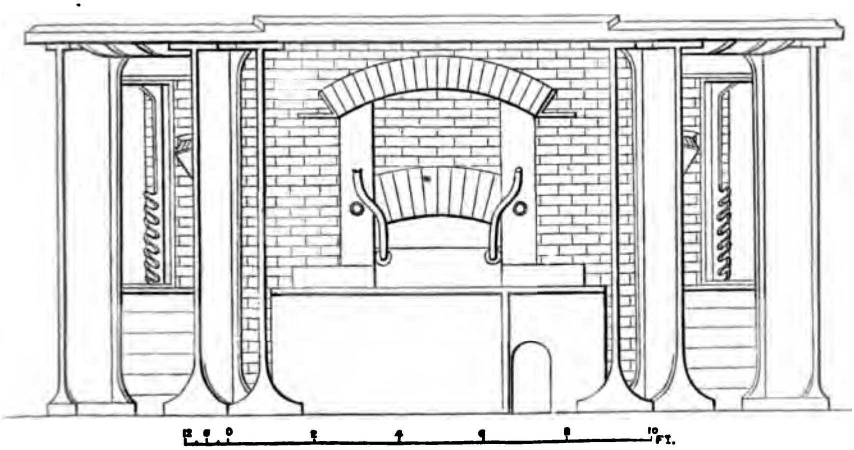


Fig. 45. Blast-furnace, Russell's Hall, near Dudley, Staffordshire. Enlarged elevation of the fore part, showing the water-tymp *in situ*, and the dam with the tapping-hole.

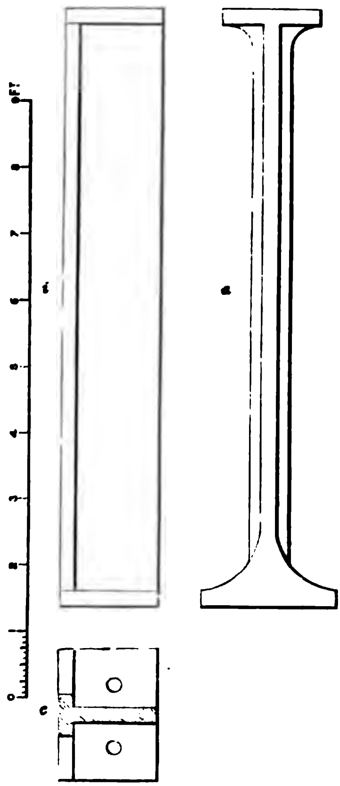


Fig. 46. Cast-iron Standards.

Figs. 47, 48, 49.—Water-Tymp.

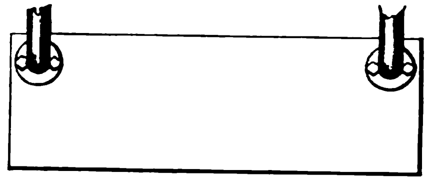


Fig. 47. Front elevation.

Fig. 48.—Longitudinal section parallel to the large surface.

Fig. 49. Vertical transverse section.

Blast-furnace, Russell's Hall, near Dudley, Staffordshire.

Blast-furnace, Ebbw Vale, Monmouthshire.—No. 1 furnace.

I am indebted to the Ebbw Vale Iron Company for the drawings from which the accompanying engravings have been executed. The construction of this furnace will be perfectly intelligible from the engravings with the addition only of a few words of explanation. There are four massive pillars at the bottom, which rest on an iron ring, fig. 51, *a a*. There are three twyer-holes, figs. 51, *c*, *c*, *c*, and the sides of the hearth under these are supported by hollow rectangular castings of iron, called water-boxes, through which cold water circulates, figs. 51, *b*, *b*. The upper part of the boshes is here clearly indicated by an angle, fig. 51, *d d*. The mouth of the furnace is fitted with what is termed the cup and cone. There is a circular opening near the top, fig. 51, *g*, for taking off the gases, and various pipes are shown for conveying them to the hot-blast stoves, fig. 52, *h h*,—*l*, *l*, etc.; but all these arrangements will be fully considered in the sequel.

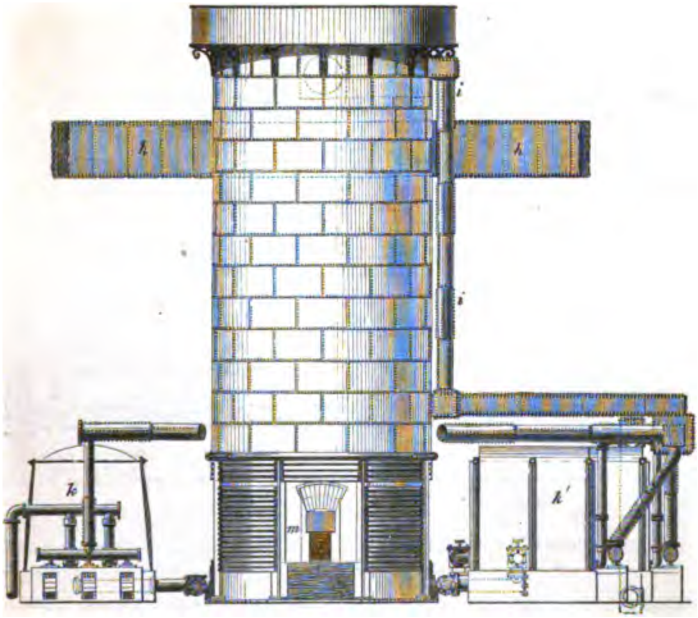


Fig. 50. Blast-furnace, Ebbw Vale, Monmouthshire. Front elevation, with hot-blast stoves, k, k', k^2.

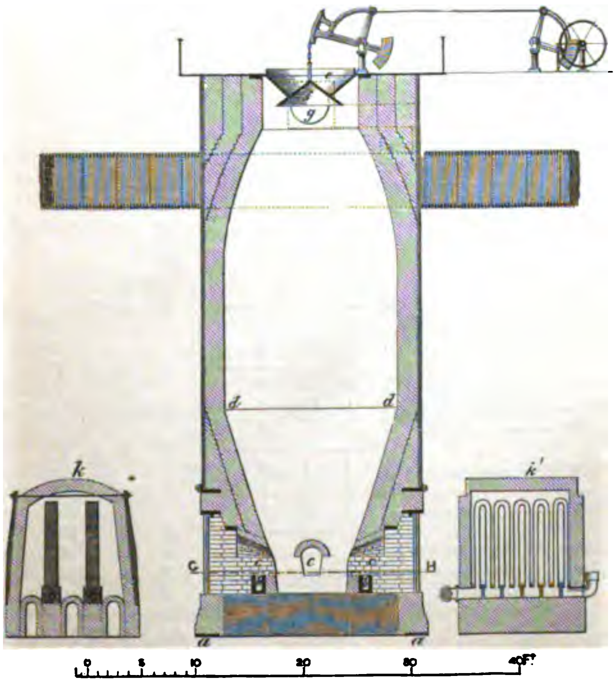


Fig 51. Blast-furnace, Ebbw Vale, Monmouthshire. Vertical section of the furnace through the centre on the line A B, fig. 52. Vertical section of the stove k on the line C D, fig. 52, and of the stove k' on the line E F, fig. 52. The stove k^2 is omitted.

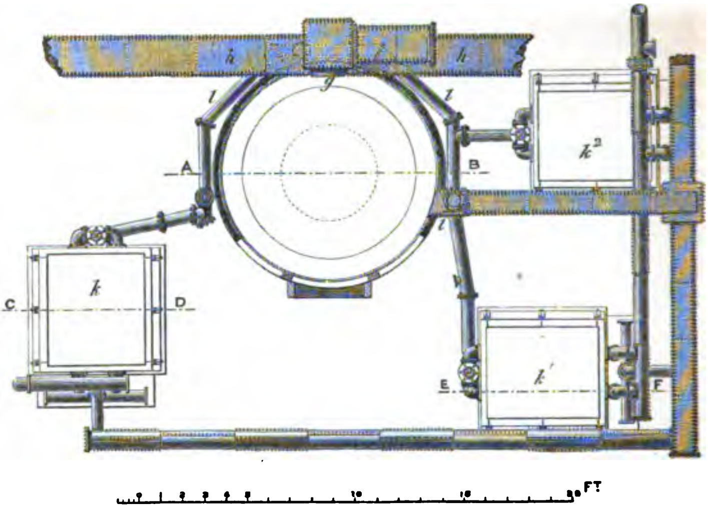


Fig. 52. Blast-furnace, Ebbw Vale, Monmouthshire. Plan.

Cost of erection.—Every item will be found in the following statement:—

CASTINGS:—	Tons.	cwts.	qrs.	lbs.	Tons.	cwts.	qrs.	lbs.	£.	s.	d.
8 Top rings	5	16	0	0							
8 Bottom rings	6	0	0	0							
8 Standards	12	8	0	0							
					24	4	0	0			
3 Water-blocks under twyers					3	16	2	0			
3 Lintels	0	13	2	0							
3 Lintel-plates over twyers	1	4	0	0							
					1	17	2	0			
1 Water-tymp	0	10	0	0							
1 Dam-plate	0	13	2	0							
2 Brackets	0	2	0	0							
					1	5	2	0			
2 Cinder-troughs } 1 Iron do. }	2	6	0	0							
1 Harp-plate[2]	0	16	1	0							
					3	2	1	0			
1 Ring on Furnace-top under cup					1	15	0	0			
1 Cup	2	5	0	0							
1 Cone	0	15	0	0							
					3	0	0	0			
2 Standards	0	9	0	0							
1 Bed-plate	0	14	0	0							
2 Bell-cranks	0	17	0	0							
					2	0	0	0			
2 Balance-weights	1	4	0	0							
1 Pinion	0	0	1	20							
1 Brake-wheel	0	2	0	20							
					1	6	2	10			
12 Brackets under stage on top					0	15	1	6			
12 Plates for do. do.					2	14	0	0			
4 Do. bridge					3	4	0	0			
At 8*l.* per ton					49	0	2	16	392	5	0

[2] Its use is to act as a fulcrum at each notch while removing the cinder by a bar of iron; but this plate has become unnecessary since the introduction of cinder-tubs. See fig. 104.

	Tons.	cwts.	qrs.	lbs.	£.	s.	d.
CASTINGS brought forward					392	5	0
WROUGHT-IRON WORK:—							
Casing of furnace	15	10	0	0			
Plates round top of stage	0	7	0	0			
Railing	0	12	0	0			
4 Girders under bridge	1	5	0	0			
96 Hoops round furnace-bottom	3	7	0	0			
192 Bolts for hoops, 420 lbs.	0	3	3	0			
At 11*l.* 10*s* per ton	21	4	3	0	244	4	7
LABOUR on casing 15 tons 10 cwts. at 95*s.*					73	12	6
Do. stage					10	0	0
Do. cup and cone arrangement					3	0	0
Do. hoops, etc., bottom of furnace					12	0	0
Do. building cupola and raising and dressing fire-stone hearth					92	0	0
BRICKS = 98,227 – 9 in. × 4½ in. × 3 in. average 7½ lbs. At 2*l.* per 1000	328	17	0	0	196	8	0
CLAY. At 5*s.* per ton	98	0	0	0	24	10	0
					1048	0	1

BLAST-FURNACE, CLARENCE IRON-WORKS, MIDDLESBORO'-ON-TEES.—Fig. 53.

For the drawing from which the engraving was executed, I am indebted to the proprietor, Mr. Isaac Lowthian Bell, of Newcastle-on-Tyne. The bottom and sides of the hearth as high as the twyers are made of "fire-stone." The stones forming the bottom are about 2 ft. thick; they are placed edgewise, and so dovetailed as to be kept down by the superincumbent weight of the furnace. There are three twyer-holes. The annular spaces shown external to the lining are not filled. The casing is of brick as well as the lining. The furnace is braced with iron hoops, and the tunnel-head with boiler plate. Three twyers are employed, the narrow openings of which are from 3½ in. to 4 in. in diameter.

DESCRIPTION OF SWEDISH BLAST-FURNACE.—Fig. 54.

In illustration of a blast-furnace in which charcoal is exclusively used as fuel, I have selected a furnace erected at Sten, near Finspong, in Sweden, in 1857. It was designed by my friend Mr. Andreas Grill for Mr. Carl Ekman, and has served as the model for other iron-smelting furnaces subsequently built in Sweden. I am indebted to Mr. Grill for the drawings from which the accompanying engravings have been executed.

A. Mine-kiln for calcining the ore, heated by the waste-gases from the blast-furnace.

B. Ore-house with compartments for storing the five different kinds of roasted ore, employed at these works. At some works the varieties of ore are more numerous.

C. Mill for crushing calcined ore.

D. Blast-furnace.

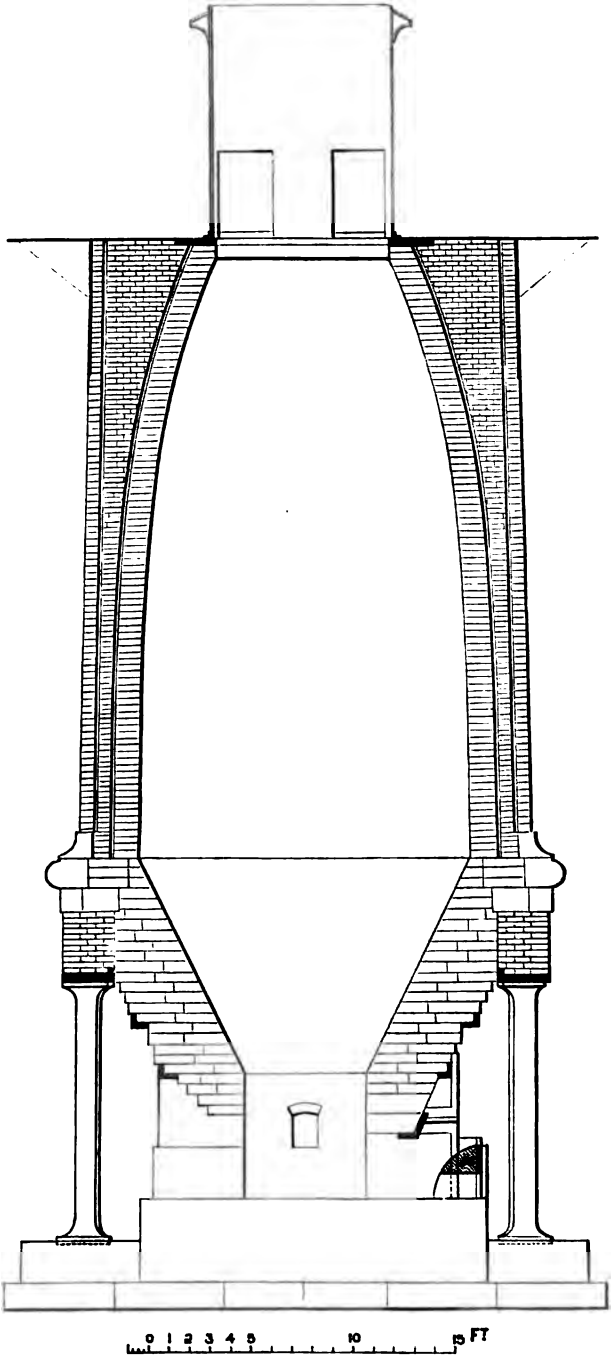


Fig. 53. Blast-Furnace, Clarence Iron-works. Vertical Section through the Dam.

Mine-kiln (A.).—*a*, *a*, *a*, *a*, openings for drawing out calcined ore. They are provided with tight-fitting cast-iron doors, with registers for regulating the admission of air. The floor of the kiln is a low four-sided pyramid, the sides of which correspond with the four doors respectively. A little above the apex of this pyramid is a horizontal ring of cast-iron, formed of four equal segments. This ring supports the lining of the upper part of the kiln. The floor and sides of the kiln below this ring are covered with cast-iron plates about 1 in. in thickness. Both the exterior and interior of the kiln are circular in section. The interior is formed of two truncated cones of equal height, the uppermost being nearly cylindrical. The lower one is made much more conical, in order to allow the ore, after it has become agglomerated into masses in the hottest part of the kiln, near the openings *c*, *c*, *c*, more easily to break up in its descent towards the bottom. The interior of the kiln, resting upon the ring of iron previously described, is of fire-brick, while the shell or outer casing is of common brick, or any other convenient material which may be at hand. The gas is conveyed from the blast-furnace through a cast-iron pipe, *e*, to the flue, *b*, *b*, which extends round the kiln. From this flue the gas passes into the interior through 12 equal and similar rectangular openings at the same level, *c*, *c*, *c*; these openings communicate also with the exterior, where they are closed by tight-fitting cast-iron doors. The admission of the gas is regulated by bricks which slide over the mouths of the short connecting passages between the flue *b*, and the openings *c*, *c*, *c*, etc. Immediately above these latter is another row of rectangular openings communicating with the exterior, through which iron bars may be introduced for the purpose of detaching any ore adherent to the lining, and the condition of the interior as to temperature, etc., may be observed. The kiln is contained within a wooden building, *u u u*, etc., in order to shelter the workmen in severe weather, and to protect the kiln itself from the influence of wind, which materially affects its working. There are three stages round the kiln, one at the top for charging, another at the bottom for drawing out the ore, and a third intermediate for facilitating operations connected with the gas, etc.; they are all clearly indicated in the engraving. The kiln is braced with strong iron hoops.

Ore-house (B.).—In fig. 2 it is shown in plan in its whole length; but in fig. 1 it is shown in vertical section much shortened. It consists of five equal rectangular compartments of brick or other suitable material; they are entirely open on one side, contiguous to the railway, *f f*; they are under a wooden roof, the top of which supports the gas-pipe, *e*. The ore is conveyed from the kiln to the ore-house in wheel-barrows.

Crushing-mill (C.).—The calcined ore is crushed between grooved cast-iron rolls, *i*, *i*, to sizes varying from ½ to 1 cubic inch. Motion is communicated by an over-shot water-wheel, *g g*, the wooden shaft of which is prolonged, and forms the axis of one of the rolls, the other roll revolving by friction of the ore. The water-tank for supplying the wheel is shown at *h*. The crushed ore is raised to the tunnel-

head up a steep incline in a wooden box, containing about 2 or 3 cubic feet of ore. The incline consists of two parallel wooden balks, each of which in section is a rectangle of about 14 in. x 8 in. The box is hoisted by an iron chain by means of the drum, *k*.

Blast-furnace (D.).—The furnace is similar in all essential respects to the English furnaces, of which a detailed description has been given. It consists of an inner lining of fire-brick, and an outer shell of non-refractory material. In the shell are two concentric annular spaces filled with sand. In the engravings, the refractory part is distinguished from the non-refractory by lighter sectional shading. The lower part of the boshes and the hearth, indicated by dotted shading, is formed of a mixture of 6 parts by measure of crushed quartz, and 1 of raw fire-clay, suitably tempered with water. It is firmly stamped down by iron bars round a wooden block, consisting of several pieces fitting one over the other. The block is afterwards removed, when the furnace is very gradually and cautiously dried by means of a temporary fire-place at the tymp, wood being used as the fuel. The bottom of the hearth rests on a cast-iron plate about 1½ in. in thickness. This plate is supported on vertical walls with spaces between them for the purpose of drainage. There are three twyer-holes, and three water-twyers on the Staffordshire principle. The blast-pipes, *q*, are of cast-iron turned externally in a lathe. The twyers are about 2½ in. in diameter, and the blast-pipes about ¼ in. less at the nozzle. The tymp, *r*, consists of a rectangular piece of cast-iron, about 1½ in. in thickness, contact with the external air keeping it sufficiently cool. The dam, *r′*, is inclined, and covered with a plate of cast-iron. The tapping-hole consists of a vertical slit, about 3 in. wide, extending from the top of the dam, where it is open, to the bottom. It is closed with sand. At the lower part of the furnace there are four large openings, of which three, *t*, *t*, *t*, correspond to the twyer-holes, the fourth, *s*, being larger, and constituting the fore part. The hot-blast stove, *l*, is formed of four horizontal rows of cast-iron pipes, one above another; it is heated by the waste-gases conveyed from the opening, *m*, in the upper part of the blast-furnace. The air-pipes are so arranged that, when necessary, the blast may enter the furnace without passing through the hot-blast stove. Nearly opposite *m* is another similar opening, from which the gases are conveyed to the mine-kiln through a cast-iron pipe, *n*. The mouth of the furnace is always left open. Through openings in the elbows of the gas-pipe, shown on each side of *e*, fig. 2, the dust, which accumulates within, may be conveniently removed. The blowing-engine consists of three single-acting cylinders, each about 45 in. in diameter, and with about a 45 in. stroke. The regulator is of sheet-iron, and is fixed over the blowing engine. Water-power is alone used. The air-pipe from the blowing-engine is shown at *o*. The exit pipe from the hot-blast stove is of cast-iron, and is shown at *p p*. Around the mouth of the furnace is a solid floor of wood, round which are compartments to receive the various kinds of ore and limestone. The upper part of the furnace is contained within a wooden building, *u u u*, of which the top of the roof is moveable,

and which is always off when the furnace is working. Without this arrangement the furnace would suffer from snow and rain when it is idle, a period which usually extends over some months in the year. The charges are accurately weighed on a steel-yard, attached to a crane, by means of which it can be swung from one part of the mouth to the other. The cast-house, facing the fore-part, is a building of wood. Staircases leading to the different parts of the works are drawn at *w, w, w*, etc.

Pressure of the blast.—In blast-furnaces in which charcoal is employed as fuel, the pressure of the blast is always much less than in furnaces worked with coal or coke. The pressure varies according to the quality of the charcoal, and the extremes are ½ and 1½ lb. per square inch. With hard compact charcoal, such as is produced from Spruce Fir (*Abies excelsa*), Beech, etc., the greatest pressure is needed, and the least with light charcoal, such as that produced from Silver Fir (*Abies pectinata*), Larch (*Larix Europæa*), etc. In every case in which magnetic oxides are smelted, the rule in Sweden is so to regulate the blast, that the contents of the furnace may not be wholly renewed at intervals of 12 hours, as it has been found by long experience that this is the shortest period in which these ores are completely reduced. With other ores, such as lake ores, complete reduction is effected in about 8 hours, but still the same rule is strictly followed.

Temperature of the blast.—It is generally about 200° C. (392° F.). But when grey foundry is required, the blast is heated to about 300° C. (572° F.). On the other hand, when cast-iron is made suitable for conversion into bar-iron, it is only raised to about 100° C. (212° F.), and hot-blast is never used for making guns or the best Dannemora iron.

General remarks on the smelting of iron in Sweden.—There are three kinds of iron-ores employed in Sweden, magnetic oxide, red oxide, and brown iron-ore. The magnetic oxide is the most widely diffused and most largely consumed. It occurs in veins in crystalline and metamorphic rocks, such as quartzite (helleflinta), granite, gneiss, mica-schist, etc., and may be associated with quartz, garnet, epidote, hornblende, augite, carbonate of lime, etc., and with from 6 % to 10 % of protoxide of manganese, or more. Some varieties require no flux, yielding a fusible slag *per se*, when the different ores are mixed in due proportions. Such are the Dannemora and Persberg ores; but, in most varieties, there is an excess of silica in the matrix, and the addition of lime as a flux is necessary. The quality of these ores is much influenced by the nature of the matrix. The best do not contain an appreciable amount of phosphorus; and it is the absence of this injurious element which especially determines their value. Iron pyrites is occasionally present, and is found in sensible proportion even in some ores of highest repute, *e.g.*, the Dannemora; but, as the sulphur is always expelled by careful calcination, it produces no injurious effect.

The red oxide is in the state of hard compact specular iron-ore, and occurs in veins in quartzose and granitic rocks, but never in limestone. The matrix is generally highly siliceous from the presence of free

silica. This kind of ore is scarcely less abundant than the magnetic oxide, and yields equally good iron. Both kinds are often smelted together. It is only from these ores that malleable iron is made in Sweden for exportation.

The most important iron mines in Sweden may, with reference to the quality of the ores, be classified as follows :—

Dannemora	Upsala County.
Persberg	Wermland do.
Bispberg	Dalecarlia do.
Nora	Örebro do.
Norberg	Westmannia do.
Taberg	Jönköpings do.

The brown iron-ore or hydrated sesquioxide is obtained from lakes and bogs, and is only used to produce cast-iron for foundry purposes, when great strength is not an object; the strongest cast-iron for heavy castings being always derived from magnetic oxide. The magnetic and red oxides are designated mountain-ores, to distinguish them from the lake and bog ores.

The mountain ores, in lumps not larger than the double-fist, are always subjected to a most careful preliminary calcination, and are afterwards crushed between rolls into pieces less than an inch square. Calcination is even resorted to in the case of magnetic and red oxides which contain no appreciable quantity of sulphur, as experience has proved that otherwise they cannot be smelted in a satisfactory manner. No good explanation of this has yet been presented. It has been supposed that the change might be merely mechanical, and might depend on the formation of minute fissures in the ore, whereby permeation by the reducing gas of the furnace would be facilitated. But it may be objected that there are rich magnetic oxides which are extremely porous prior to calcination, and very dense or even vitreous afterwards; and yet it is alleged that such ores equally require calcination. Calcination is now everywhere carried on in Sweden by means of the waste-gases, by which fuel is greatly economized, and the process conducted in a more efficient manner. The blast is also generally heated by the same means, and in a few instances, likewise, the boilers of steam-blowing engines.

The only flux used for the mountain-ores is limestone, and it is sometimes added to the extent of 30 % of the weight of the ore, but generally the proportion ranges from 10 % to 15 %. With the lake-ores diorite or greenstone is used as flux, but only from want of limestone in the districts.

When cast-iron for foundry purposes is required, it is sought to produce a slag of the formula RO,SiO^3; but for conversion into malleable iron, the slags should be composed according to the formulæ $3RO,SiO^3$ or $3RO,2SiO^3$, or any intermediate formulæ. As an example of a good slag or cinder of an intermediate formula, may be cited one from Edsken, which was analysed by Professor Ullgren, of Stockholm, and found to have the following composition :—

		Oxygen.	
Silica	46·37		24·08
Alumina	4·30		2·01
Lime	38·64	11·04	14·72
Magnesia	7·40	2·96	
Potash	0·30	0·05	
Soda	0·14	0·04	
Protoxide of iron	0·95	0·21	
Protoxide of manganese	1·86	0·42	
Copper	trace.		
Sulphur	0·03		
Phosphorus	trace.		
	99·99		

The cinder generally flows exceedingly thin and well, and contains under 1 % of iron, thus showing how completely the ore is reduced.

The average yield of the ores is 50 %, and the quantity of charcoal consumed in producing 1 ton of cast-iron does not usually exceed 1 ton; it is often as low as 0·8 ton, or about 200 cubic feet (Swedish), and sometimes less. From 30 to 50 cubic feet are charged at a time. Great attention is paid to the charging of the ore. From 7 to 10 cwts. of ore are introduced at a time on the top of the charcoal, half being spread evenly round the sides and the other half in the middle. The twyers should not be too "bright," and there should be short slag prolongation, or "nose," at the end of them. With the proportions above given, these defects are usually avoided. The most siliceous ore should be placed in the first position, and the most calciferous in the last. The limestone, in pieces of the same size as the ore, is thrown evenly over the latter; it is crushed in the same mill as the ore. During working, the fore part is stopped with sand in about the same degree as English furnaces in which coke or coal is used.

Hot-blast is used in every blast-furnace, except those of Dannemora, and in those in which cast-iron for ordnance is produced.

The furnaces are usually tapped at intervals of 6 hours, and the average make per week is from about 40 to 60 tons (of 2240 lbs.). The metal is run into iron moulds, and not into sand.

Mottled pigs, half grey and half white, are used for conversion into malleable iron. In puddling, grey-iron is employed without having been previously treated in the refinery or running-out-fire. The temperature, however, required to puddle the best sorts of pig-iron is so high that it is difficult to procure materials sufficiently refractory for the sides of the furnace. All the pig-iron made at Dannemora is white and largely crystalline, owing to the richness of the ores in manganese.

In Sweden every means is adopted to economize fuel and to produce metal of the best quality, irrespective of quantity or time. The furnaces are small in comparison with English blast-furnaces, and inexpensive in construction. The forms of the interior vary much; but that of which an engraving has been given is considered to be the best. Each iron-work has peculiar marks for its pig-iron, as well as for its bar-iron, and the same mark is not always used for both even at the same work. Since the exportation of the former has

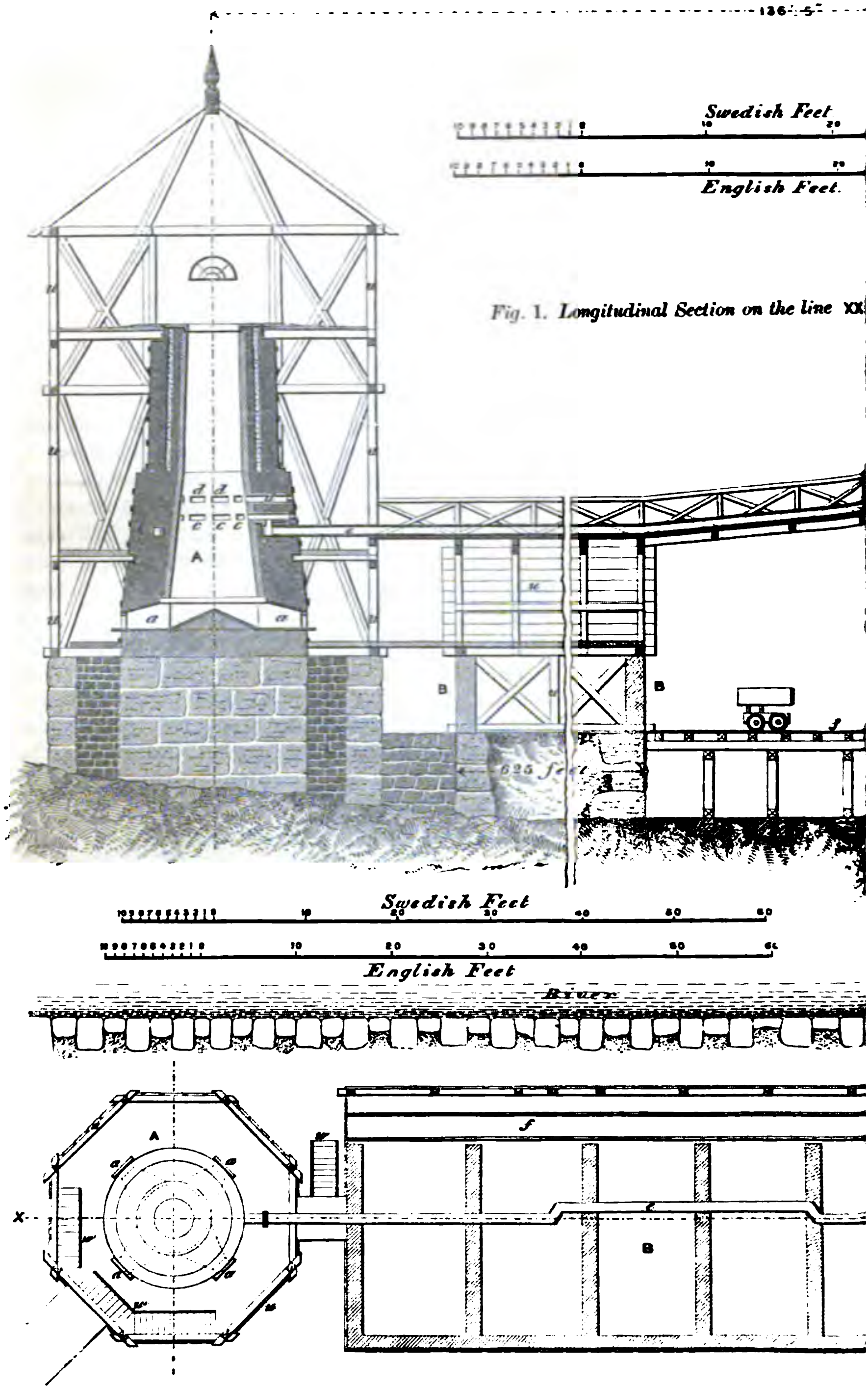
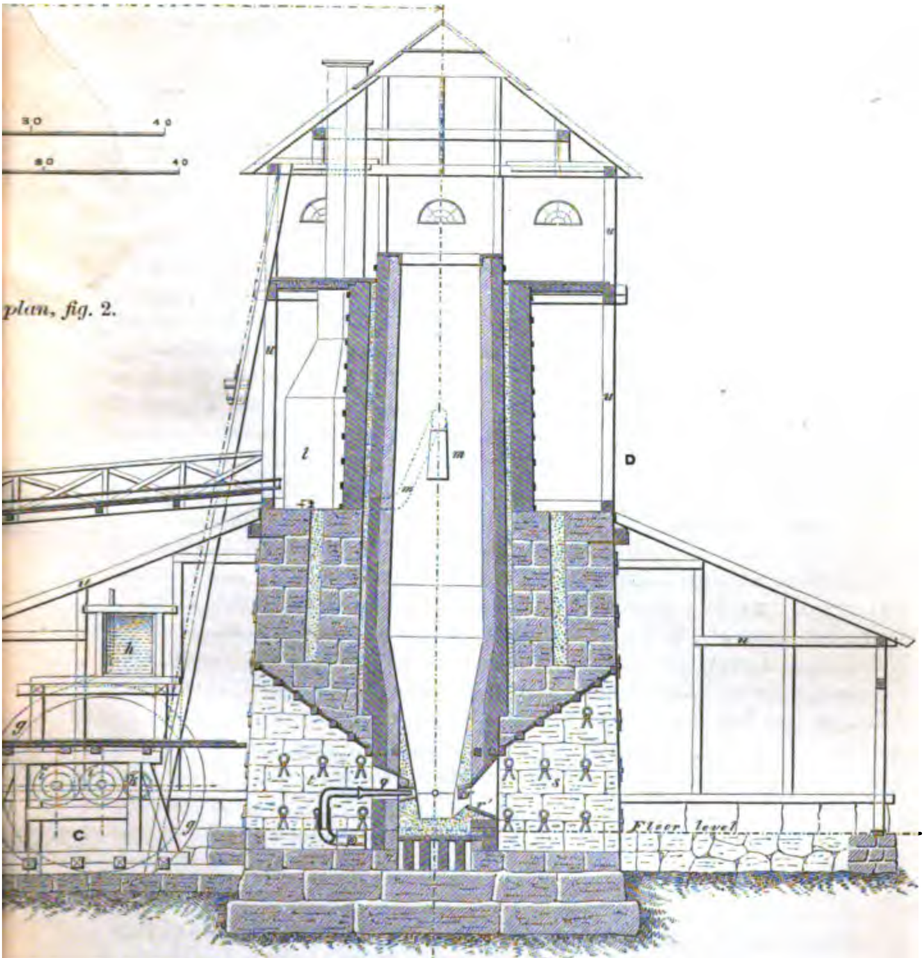


Fig. 54. Swedish Blast-furnace.

plan, fig. 2.



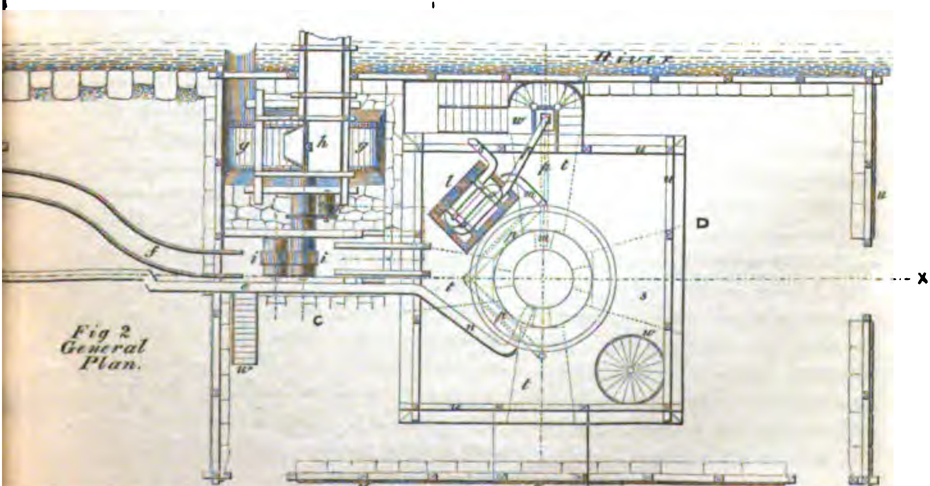


Fig 2
General
Plan.

only recently been allowed by the Swedish Government, it is important that particular attention should now be directed to the marks thereon, as the quality of the metal from different works varies considerably.

Smelting of Lake and Bog Iron-Ores in Sweden.

These ores are only smelted when pig-iron is required suitable for castings, in which great strength is not essential. For this purpose the molten metal should be very thin and liquid, so that it may run well into the mould, and take even the most delicate impressions; and as the pig-iron derived from this class of ores is generally rich in phosphorus, it possesses when in a molten state a great degree of liquidity. The lake-ores occur naturally in so finely divided a state as not to require any mechanical preparation; but the bog-ore when in lumps is broken with a hand hammer into pieces of the same sizes as the mountain-ores. These ores are never calcined previously to smelting. The blast-furnaces in which they are treated only differ from those employed in smelting mountain-ores in having less altitude. Generally no flux is needed; but occasionally, when much silica is present, from 1 °/₀ to 3 °/₀ of limestone is added, or, as in some localities limestone is very scarce and expensive, a variety of hornblende, rich in magnesia and lime, is used as a substitute. Such a variety, occurring in Sweden, has the following composition[3]:—

Silica	58·87
Alumina	1·77
Magnesia	28·19
Lime	11·00
Loss by calcination	0·18
	100·01

These ores, which consist essentially of hydrated sesquioxide of iron, are, for reasons previously advanced, much more easily reducible than the mountain-ores; and the contents of the furnace may be completely renewed in 8 or 10 hours, instead of 12, as in the case of the latter description of ores. Considerable difficulty is experienced in the smelting of lake-ores, owing to the fact that a large proportion of them is in a pulverulent state, and the course of the blast through the furnace is impeded in consequence. This evil may, in a certain degree, be counteracted by using dried wood to the extent of $\frac{1}{8}$ of the volume of the charcoal. It is only in Småland, in the south of Sweden, that these ores are smelted, and the pig-iron produced from them is exclusively used in the country. The average yield of these ores may be estimated at about 27 °/₀, and the average weekly make at 20 tons per furnace (ton of 2240 lbs.), with a consumption of from $1\frac{1}{2}$ to 2 tons of charcoal per ton of pig-iron. The blast is heated to 300° C., in order to economize fuel, but especially with a view of carburizing the iron sufficiently for foundry purposes by remelting. The fracture of the pig is usually dark-grey, but never so coarse-grained as Scotch pig.

[3] Analysis by Rammelsberg, Handb. der Mineralchemie. 1860. p. 469.

Usually, in Sweden, to each blast-furnace is attached a forge, and both belong to the same proprietor. However, in a few instances, the blast-furnace is owned by a proprietary of from 15 to 20 persons; and, as the proprietors are individually engaged in working iron mines and burning charcoal on their own account, so they also smelt individually on their own account. Thus the ore belonging to different individuals is separately smelted, as far as practicable, in the furnace in which they have shares, each supplying his own charcoal; just as a farmer might convey his wheat to a joint-stock mill, of which he is part proprietor, and receive it back in the state of flour. The same furnace, at the same instant of time, may contain ore belonging to two or even three proprietors. The pig-iron is duly apportioned to the owners of the ore from which it has been respectively derived. The parcels of ore smelted in succession may vary considerably, and in that case there will necessarily be a corresponding variation in the quality of the pig-iron produced. It may easily be conceived that such a custom must be highly disadvantageous in an economical point of view; and, accordingly, it is now nearly extinct.

The Swedish iron-master has to contend with many difficulties which are unknown to our own. His only fuel is charcoal, of which a single furnace rapidly consumes a very large amount. Hence, it is desirable not to establish two furnaces on the same spot; for in that case the surrounding country would be very quickly disforested, and it would be necessary to fetch the charcoal from a considerable distance, at a greatly increased cost of transport. In Sweden, moreover, water-power can alone be employed economically. The Swedish iron-master, therefore, requires a peculiar combination of special conditions in the locality of his furnace,—there must be the ore, the timber, and the water. But he is further exposed to casualties arising from the weather. In most works, it is only during winter that the ore and charcoal can be economically conveyed in sledges over snow on land or ice on lakes. If frost fail, as was the case last winter, the roads become comparatively impassable, and the furnaces cannot be duly supplied with material. Nevertheless, the labouring population dependent on the smelting and manufacture of iron must be maintained. They are, like the iron-works, sparsely scattered over the country, and they have not, with us, the same facilities of changing their places of abode. The Swedish iron-master engages his workmen by the year on the system of piece-work; but if operations should be suspended from one cause or other, *e. g.* unfavourable weather, they receive wages on account of any labour they may be set to perform, unconnected with the smelting and manufacture of iron. The Swedish iron-master has naturally the strongest interest in preventing the dispersion of his skilled operatives; for otherwise the quality of his iron might be subject to considerable variation, and his reputation suffer in consequence. At the present time, in Sweden, labour is paid at about half the rate of England. On the other hand, living in Sweden costs only about half as much as in England. The actual condition, therefore, of the labouring man in both countries, so far as

relates to his power of obtaining the necessaries of life, should be about the same. Mr. Grill informs me that, nevertheless, the fare of Swedish labouring men is not half so good as that of the same class in England.

Anthracite Furnaces of the United States.

I am indebted to my friend, Professor George Brush, of Yale College Connecticut, for photographs of drawings from which the accompanying lithographs have been executed; and to Professor Lesley, author of the valuable and well-known work on the Iron-making Resources of the United States, for the following description.

The Thomas[4] Iron Company's furnaces stand on the banks of the Lehigh river, a mountain stream, about as large as the Thames, which drains the broad summit of the Cattskill or Pocono Mount, between the Valley of Wyoming and the Valley of the Delaware, as well as all the valleys which separate the eastern anthracite coal basins. The Lehigh river flows through the heaviest anthracite iron region of Pennsylvania; furnishing with fuel, by means of its canal and its railroad, first the Lehigh Valley furnace, then the two Thomas Iron Company furnaces, then the five Crane Company furnaces, then the four Allentown Iron Company furnaces, with the fine new Rolling Mill of Haywood and Company. At Allentown the river strikes the foot of the South Mountain, turns at a right angle towards the north-east, and follows the foot of the mountain, past Bethlehem with its zinc-works, the three Glendon stacks [*i.e.* furnaces] and Rolling Mill, and the South Easton furnaces, to Easton, opposite to which stand the three Phillipsburg furnaces; while a few miles farther down, on the west bank of the Delaware, are the Durham furnaces.

Most of these works are of the largest class; they vary from 14 ft. to 22 ft. across the boshes, and are from 45 ft. to 60 ft. high, making from 8000 to 12,000 tons of pig metal per year. Their ores are brown hæmatite dug from the outcrops of the Lower Silurian limestone, which forms the southern half of the Great Valley behind the South Mountain; but mixed with these are magnetic ores brought from the prolongation of the South Mountain anticlinals through New Jersey.

It was at Mauch Chunk, in the gorge of the Second Mountain, through which the Lehigh breaks out of the Coal region, that the first experiments were made to smelt with anthracite, a dozen years before Mr. Thomas came over from Wales and blew in the Pioneer Furnace, at Pottsville, on the Schuylkill, in 1837. As soon as success was secured, and while Mr. Thomas was building the Crane stacks on the Lehigh, anthracite furnaces were started on the Lower Schuylkill, not many miles above Philadelphia; and the two rivers have ever since kept up a rivalry in the manufacture; the Lehigh bringing down the hard pure coals of the Beaver Meadow, Hazleton, and Mauch Chunk mountains, and the Schuylkill furnishing its furnaces with the softer coals of the Pottsville basin. In course of time furnaces were

[4] Mr. Thomas, who established these works, was formerly employed at the Yniscedwin furnaces near Swansea, where anthracite was first used to smelt iron by the late Mr. Crane.

built along the Susquehanna river also, and supplied with the still softer anthracites of the Shamoken, the Bear Gap, and the Swatara fields; the western termini of the same basins, which, in their central portions, feed the Schuylkill, and at their eastern ends the Lehigh.

But the grey magnetic ores of the South Mountain between the Schuylkill and the Susquehanna rivers now came into play. That wonderful deposit at Cornwall, near Lebanon, has been the chief dependence of at least twenty stacks; furnishing a magnetic mixture for the Lower Silurian brown hæmatites of Lancaster county, and also for the Upper Silurian red fossil ore of Danville and Bloomsburg on the northern side of the anthracite country.

In 1854, the production of anthracite iron in the region described was 200,000 tons, besides another 100,000 produced in New York, New Jersey, and Maryland.

In 1856, the production of anthracite iron in Pennsylvania was 307,000 tons, besides 87,000 produced in the other three States named.

In 1857, the financial crisis came; the production of iron fell somewhat off through 1858, but recovered itself in 1859. The war broke out in 1860, and has stimulated the manufacture to such an extent, that the whole make of iron in the United States, which was 725,000 tons in 1854, and 813,000 tons in 1856, is supposed this year to be about 1,000,000 of tons. The depression of the manufacture just previous to the laying of the new tariff and the opening of the war, had a beneficial effect in instituting close and radical economies, especially touching the *personnel* of superintendence and the careful selection of the most skilled labour. It was high time; for these economies alone could have kept up the manufacture in the face of the old tariff; and their effects are still more observable now that prices of labour in the mills and about the stacks have gone up from 50 to 100 per centum.

In the Pittsburg region, while the manufacture of steel has at last made a secure lodgement, the discovery of a good raw coal bed, near the base of the Coal Measures, has established the manufacture of raw coal iron on the Alleghany river, in the Clarion County neighbourhood, where between forty and fifty charcoal furnaces used to be in blast, all which are now out, for want of fuel. The raw coal iron is made from the same great bed of brown hæmatite overlying the buhrstone and limestone, which runs through that part of Pennsylvania, through Eastern Ohio, into Kentucky. This iron is now pronounced superior to the charcoal pig for Pittsburg use.

In the neighbourhood of Youngstown, and again near Zanesville, Ohio, the same ores, mixed with common clay iron-stone and with Lake Superior magnetic oxide, have been smelted with raw coal from the same bed, known as Tod's Bed, for several years; but the quality of the iron has not been superior.

There were forty-five charcoal furnaces in Western Kentucky and Western Tennessee, in what is known as the Eddyville and Clarkesville region, which made 50,000 tons per annum; but the manufacture

was killed by the insurrection among the slave hands, on Christmas and New Year of 1856; and, reviving under the necessity which compelled the leaders of the great Rebellion to make iron wherever it could be made, it has again succumbed under the reoccupation of the district by the national armies and the irregularities of a guerilla warfare.

The iron-works of East Tennessee have suffered from the same cause, but those of North Carolina, and especially those of the Dahlonega region in Northern Georgia and Eastern Alabama, have been stimulated to unwonted activity. Northern Georgia now furnishes the Rebellion with rails, machinery, locomotives, field and siege guns, and small arms, as well as articles of manufacture not requiring iron. Atlanta is the heart and lungs of the Rebellion, as Richmond is its brain. The workmen at Atlanta have succeeded in doing what is perhaps a unique feat in iron-work; they have machinery for cutting out the ruined parts of a rail and inserting a new piece.

With regard to the future of the Southern iron manufacture, there can be no doubt of its indefinite and rapid increase. There is more fine iron-ore in North Carolina than in any other State of the Union; and although there is but one small coal basin in the State, the Deep River Basin, with one small double coal bed full of sulphur and parted by a two-foot bed of iron-ore full of fish-teeth and phosphorus, while the Dan river coal basin projects its point only across the border from Virginia, yet a plate of coal measures containing several beds of coal covers the whole plateau of the Cumberland Mountains in Eastern Tennessee, and railroads through the Black Mountains and the Smoky Mountains will bring the stock and fuel together. A system of free labour will do the rest.

In the North, the indefinite expansion of the Anthracite iron manufacture is equally certain, whatever may be the policy of the government or the results of the present civil war. The wonderful iron-ore wealth of New Jersey has hardly yet been explored; and another anthracite iron region about Morristown would already have been added to the rest, had there been any direct facilities for bringing the coal to the ore. Now that the Carbondale or Wyoming Coal basin, and the Mohanoy or Middle Coal basin, have both been opened up to the Hudson river market, the vast magnetic ore beds of Lake Champlain will have many more high stacks erected near them than those which already stand upon the shore. Some of these are noble works, mounted on iron pillars. But the principal manufacture must always cling to the Lehigh and Schuylkill, and Lower Susquehanna valleys in Pennsylvania, where the ore is abundant, the coal near at hand, and the flux on the spot; where the whole land is a garden, and therefore food cheap and labour plentiful, and the great sea-ports not far off. For all these considerations, as well as for beauty, size, and convenience of build, and for its historic interest, the Thomas furnaces, which have been selected as illustration of the American manufacture for this work, stand pre-eminent.

References to Plans as Lettered and Numbered.

Fig. 1 is a vertical central section of the furnaces and appurtenances, showing on the left side the section of an entire furnace, the gas-chamber of the furnace on the right side connected with the boiler-furnace, together with the boiler-furnace, boilers, and smoke-stack on the right and centre; the hot-blast furnace, bed-pipes, syphon-pipes, and gas-chamber connected therewith on the left side (except the blow-pipe, one twyer, water-supply and waste pipes at the furnace, and portions of the left division of the hot-blast, which are represented enclosed, with openings showing their interior).

Fig. 2 is a horizontal section, in line of C, fig. 1, showing sections of the twyers, blow-pipes, water-tanks at twyers, walls, and iron posts of furnace and abutments; with dotted lines representing the blast-pipe and water-supply pipe extending around the outside of the furnace.

Fig. 3 is a horizontal section in line of D, fig. 1, showing the hearth, iron posts, brick and mason work of furnace, and the cast-iron foundation-ring to which the lower ends of these posts are attached, together with the water-supply and waste pipes.

Fig. 4 is a horizontal section on lines A and B of fig. 1, showing as follows:—

1st. On the right, sections of the gas-chamber, apertures connecting with the furnace and flues from it to the boiler-furnaces and hot-blast ovens; also the flues of the lower section of the hot-blast oven (with the chimneys of this oven, and hot and cold air pipes in dotted lines).

2nd. In its central part, the sections of the upper range of boilers and smoke-stack, and the walls of the boiler-furnace; and, in dotted lines, the grating for temporary firing to heat the boilers.

3rd. On the left, a section of the wall of the main furnace and flue to the furnace of boilers (with dotted lines showing the smoke-stack; the position of the syphon pipes as they are attached to the bed-pipes of the hot-blast, and the flue from the gas-chamber to the hot-blast oven; also the rectangular flues running parallel to the bed-pipes, and opening into the arched flues extending across the hot-blast oven; and the buck-staffs on the outer side-walls), and also the walls of the hot-blast oven, the arrangement of the bed-pipes and the gas-openings from the flues below to the ovens above the bed-pipes, together with the cold and hot air pipes leading into and out of them.

Note.—The air-receiver delineated in the front elevation, and partly covering the arches, is 228 feet long and 6½ feet in diameter.

Similar letters represent corresponding parts in all the figures. The arrow-points show the direction of motion of the currents of water

used for cooling the twyers, etc., as also that of the air and gas. A, B, C, D are horizontal lines through the sections of the furnaces and their appliances.

a	The bosh of the furnace, 18 feet diameter.
a^2	The hearth of ditto.
b, *b*, etc.	Gas-passages recessed in the walls of the furnace, and growing deeper as they approach the apertures *c*, *c*, etc. (the dotted lines in the vertical section of the main furnace showing the continuation of the main walls of the furnace to its throat above these apertures).
c, *c*, etc.	The gas apertures from the main furnace to the gas-chamber. They are arched at the top.
d, *d*, etc.	Gas-chamber.
f, *f*, etc.	Flues from the gas-chamber to the hot-blast oven.
e, *e*, etc.	Ditto ditto boiler-furnaces.
g, *g*, etc.	Partition-walls in the gas-chamber, which are placed so as to connect three gas apertures with that part of it which supplies the hot-blast oven.
h, *h*, etc.	Longitudinal arched flues under the bed-pipes.
i, *i*, etc.	Arched flues extending across under the same.
k, *k*, etc.	Bed-pipes.
l, *l*, etc.	Rectangular flues extending parallel to the bed-pipes, and connecting the arched flues with the apertures *m*, *m*, etc.
m, *m*, etc.	Apertures from the flues under the bed-pipes to the oven above them.
n, *n*, etc.	Syphon-pipes for heating the blast.
o, *o*	Cavity of the hot-blast oven.
p, *p*, etc.	Chimneys of the hot-blast oven.
q, *q*, etc.	Cold-air pipes.
r, *r*, etc.	Hot-air ditto.
s, *s*, etc.	Buck-staffs.
t	Blow-off pipe.
u, *u*, etc.	Twyers.
v, *v*, etc.	Main blast-pipe.
w	Blast-pipe surrounding the furnace.
x, *x*, etc.	Water-supply pipes.
y, *y*, etc.	Ditto waste ditto.
z, *z*, etc.	Blow-pipes.
b^2, b^2, etc.	Bottom of the hearth.
c^2, c^2, etc.	Posts surrounding the wall outside the hearth of the furnace.
d^2	Cast-iron foundation ring.
e^2	Cast-iron flanged ring at the top of posts c^2, c^2, and on which the lining of the furnace rests.
f^2, f^2, etc.	Cross wall under the boilers.
g^2, g^2, etc.	Furnace used to heat the boilers when the gas is not sufficient.

h^2	Grate-bars.
i^2, i^2, etc.	Boilers, of which there are six in each of the furnaces in the upper tier and four in the lower tier.
k^2, k^2, etc.	Boiler furnaces. l^2, l^2 Smoke-stacks.
n^2, n^2, etc.	Water-tank at twyers. m^2 Tunnel-head.
o^2	Iron cross-beams supporting the boilers.

RESULT OF NO. 1 FURNACE OF THE THOMAS IRON COMPANY DURING LAST BLAST, FROM JULY 23RD, 1859, TO FEB. 15TH, 1863. (186 WEEKS.)

	Tons.	cwts.	qrs.
Amount of No. 1 iron made	16,057	..	..
,, 2 ,,	27,418	18	3
,, 3 ,,	2,724	..	..
	46,199	13	3

	Tons.	cwts.	qrs.
Average amount per week	248	7	3

	Tons.	cwts.	qrs.	lbs.
Amount of coal consumed per ton of iron	1	19	3	0
,, ore ,,	2	2	0	25
,, limestone ,,	1	9	0	25

Amount of cinder discharged per ton of iron 1 ton 15 cwts. 2 qrs 6 lbs.
,, blast used per ton of iron .... 810,352 cub. ft.
Average temperature of blast .... 630° Fah.
,, pressure of air .... 7½ lbs. to sq. in.

After the furnace was blown out, the lining was found to be worn very regular, but almost entirely gone, so that the average thickness would be about 4 in. There were two holes broken entirely through the lining, through which the gas escaped, which necessitated the blowing out of the furnace.

BLOWING ENGINES AND BLAST APPARATUS.[4]

The arrangements necessary for the important object of supplying artificial blast to smelting and other furnaces have long occupied the attention of mechanicians. These machines have been made in several ways, but the only kinds generally used in Great Britain are the fan and the piston machines.

The fan is used for foundry cupolas and smiths' hearths, where only a small pressure is necessary, as it is incapable of impressing much force on the air.

For refining and smelting furnaces, where a pressure is required of 3 to 4 lbs. per square inch, the piston machine is at once simple and efficacious, and is universally employed.

It is usually driven by steam power, and consists merely of a piston working in a closed cylinder; which being worked by the reciprocating

[4] The drawings of the blowing engine and apparatus have been furnished by the makers. For the description and calculations I am chiefly indebted to my friend Mr. Wm. Pole, F.R.S., Professor of Civil Engineering in University College, London.

motion of the steam-engine, alternately inhales and expels the air at both ends.

The simplest arrangement is to place the steam and blast cylinder horizontally, with their axes in the same line, and to work both with the same rod, using a fly wheel as a regulator.

The horizontal arrangement is however only suitable for blast engines of comparatively small size; when larger dimensions are requisite, the horizontal position of the cylinders is disadvantageous and inconvenient; and it is customary to place both the steam and blast-cylinders vertically, one at each end of a beam. Nearly all the large blast-engines of this country are constructed in this manner. I shall give details of the arrangement of one of these farther on.

Some years ago an ingenious engineer, Mr. Archibald Slate, proposed some modifications in blast-engines, which he considered would be of advantage. He made them smaller than usual, and worked them at a quicker speed, making thereby a small engine do the work of a large one; and as the huge size of the ordinary machines rendered them and their houses very expensive, the proposed modification seemed tempting. Moreover, he did away with the leather valves, and substituted what he considered the more mechanical form of metallic slides. Several blast-engines on this plan were erected, and are still at work; but experience has not confirmed the advantages expected. The diminution in cost by working at high speed is dearly purchased, owing to the greater wear and tear and the more liability to derangement; while the metallic slide valves, by their great surface, cause great friction and give much trouble.

As an example of the kind of blast apparatus most commonly used in this country for iron-smelting furnaces, I give engravings and a description of that erected at the Shelton Colliery and Iron-works, near Stoke-upon-Trent.

Fig. 55 is a side elevation of the engine; fig. 56 an end view; and fig. 57 a section of the blowing cylinder.

The blowing engines, of which there are two, placed side by side in the same house, were made by the Haigh Foundry Company, of Wigan in Lancashire. They supply blast at present to four furnaces, but are calculated ultimately to blow six. They are of the kind known as condensing beam engines.

The steam cylinders are 45 in. diameter, and 9 ft. stroke; and, at present, while blowing only four furnaces, they make 16 double strokes per minute.

The blowing cylinders, attached to the opposite ends of the beams, are 100 inches diameter, and have a stroke of 9 ft.

The steam and exhausting valves are on the Cornish principle, worked by cams and tappets, which are so arranged as to cut off the steam at either one-third, one-half, or three-fourths of the stroke, as may be required.

The beams are of cast-iron, each made in two parts, firmly bolted together, and bored out to receive the gudgeons. The length from the centre line of the steam cylinder to the centre line of the blowing

cylinder is 30 ft., and from the centre line of the steam cylinder to the centre of the end gudgeon for the connecting rod (measured horizontally) is 5 ft.

In order to regulate the motion, the two engines are connected to

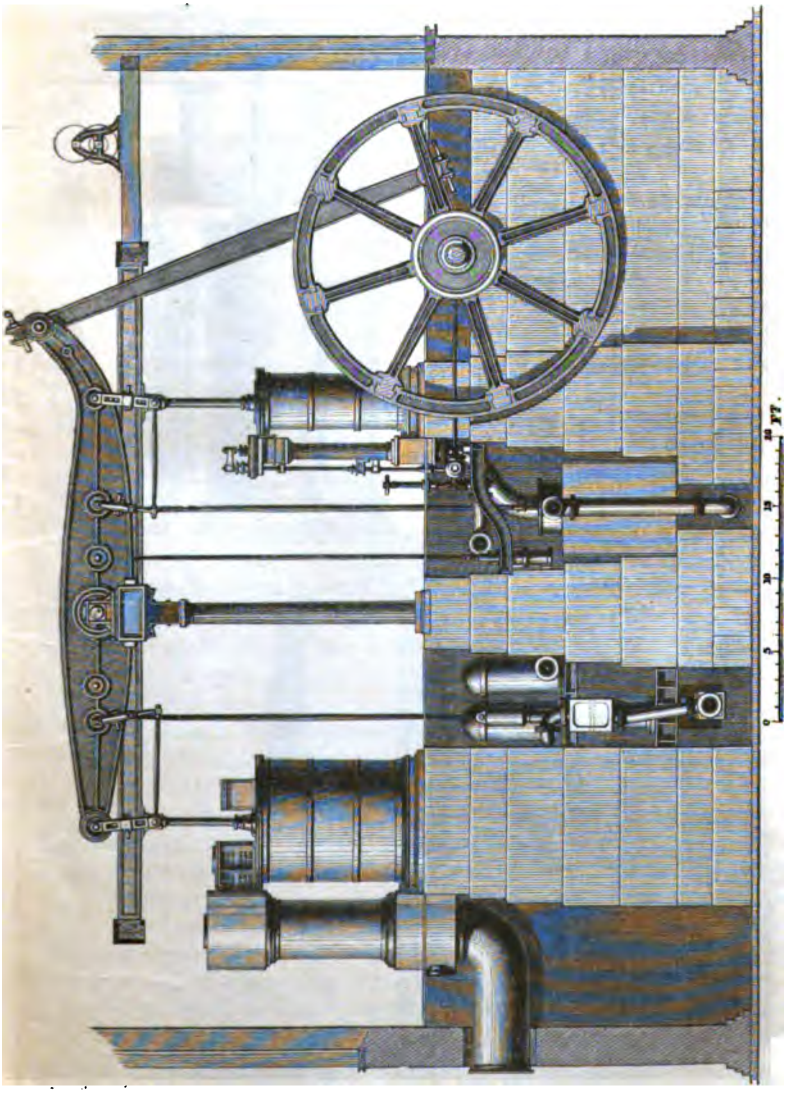


Fig. 55. Blowing engine, Shelton Colliery and Iron-works. Side elevation.

one fly-wheel shaft. This is placed behind the steam cylinder at a sufficient distance to enable the connecting rod to work clear; and in order to avoid an undue length of beam, and at the same time to adapt the line of gudgeons to the oblique position of the connecting rod, the

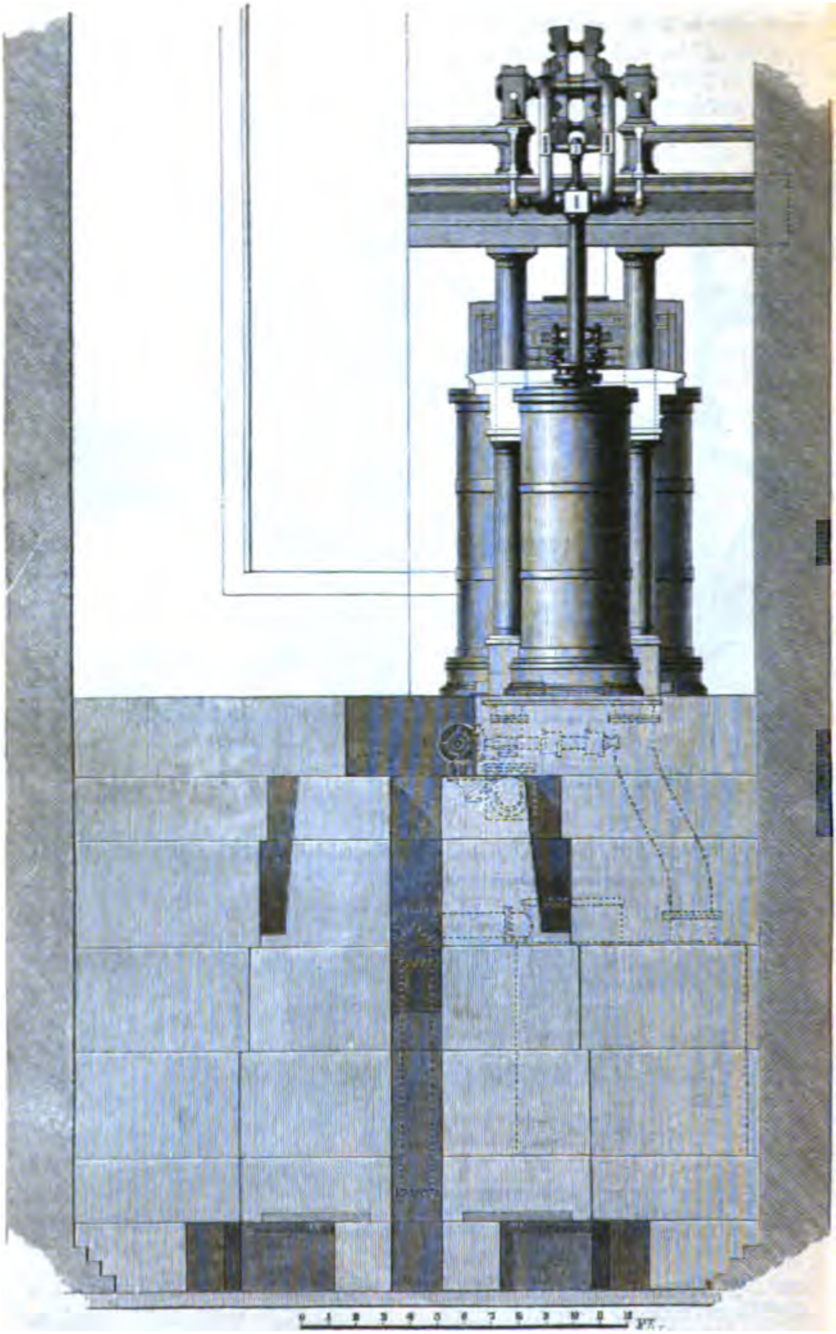


Fig. 56. End View. The portion left white behind the top of the cylinder is a mistake on the part of the engraver. Several details have been purposely omitted both in figs. 55 and 56, in order to avoid confusion.

end gudgeon of the beam is raised 4 ft. above the centre line: this also gives a good length of connecting rod without placing the crank shaft much below the ground.

The connecting rods are 24 ft. long; they are made of English oak, strengthened with wrought iron; the transverse section of the wooden rod is 15 in. by 12 in. in the middle, and 8 by 8 at the ends.

The fly-wheel is 23 ft. diameter, and the weight of the rim is 12 tons.

There are seven boilers, six of which are worked together, one being always out of use for the purpose of being cleaned. The pressure of steam in the boilers is ordinarily about 30 lbs. per square in. above the atmosphere.

Four of the boilers are 7 ft. diameter and 30 ft. long, with two internal flues in each, 2 ft. 8 in. diameter, the fires being in the flues. The other three boilers are each 5 ft. diameter, and 34 ft. 6 in. long, with hemispherical ends, and the fire grates underneath them.

There is a ram pump attached to each engine, 12 in. diameter, and 4½ ft. stroke, for supplying the twyers with water.

The cost of the two engines was about 6000*l.*, exclusive of the boilers, buildings, and stonework for the foundations.

The apparatus connected with the blowing cylinders will be best seen by the section Fig. 57: *a*, *a* is the cylinder; *b* the piston, secured to the rod, *c*, by a cotter, *d*; *e* and *f* are the inlet valves to admit the entrance of the air above the piston. The two boxes projecting from the top cover of the cylinder have numerous openings in their vertical surfaces; inside the boxes (on two sides of the smaller and three sides of the larger) are hung a number of leather flap valves, which, when resting in their natural positions, lie against the faces and cover the openings, but which open inwards when the motion of the piston downwards causes an in-draught of air.

The inlet valves for the space under the piston are shown at *h*, *i*, and *k*; the bottom of the cylinder is pierced with numerous openings, on the upper surfaces of which other similar leather flap valves lie: these rise in like manner to admit the air when the piston ascends.

The outlet valves for the top of the cylinder are shown at *g*, a range of leather flap valves being hung on the fourth side of the large box on the top of the cylinder; these valves open outwards; consequently when the piston descends, and the atmospheric air is being drawn into the cylinder, they remain closed. But when the piston begins to ascend, it first closes the inlet valves, and then compresses the air till it arrives at a pressure greater than that contained in the outlet pipes, *m*, when the outlet valves, *g*, open, and permit its exit.

l, *l* are the outlet valves for the bottom part of the cylinder, which act for the downstroke in a manner analogous to those just described.

The aggregate area of the inlet valves for each cylinder is 20 square ft.; of the outlet valves, 9 square ft.

m, *m* is the outlet pipe by which the compressed air is carried away. It is made of large size, that as little resistance may be offered as possible to the air's motion.

The arrangements for conveying the blast to the furnaces, and for heating it, are of the usual kind.

From the blowing cylinders the air passes by the two pipes (already mentioned), *m*, *m*, along a main conduit, of wrought iron, 112 ft.

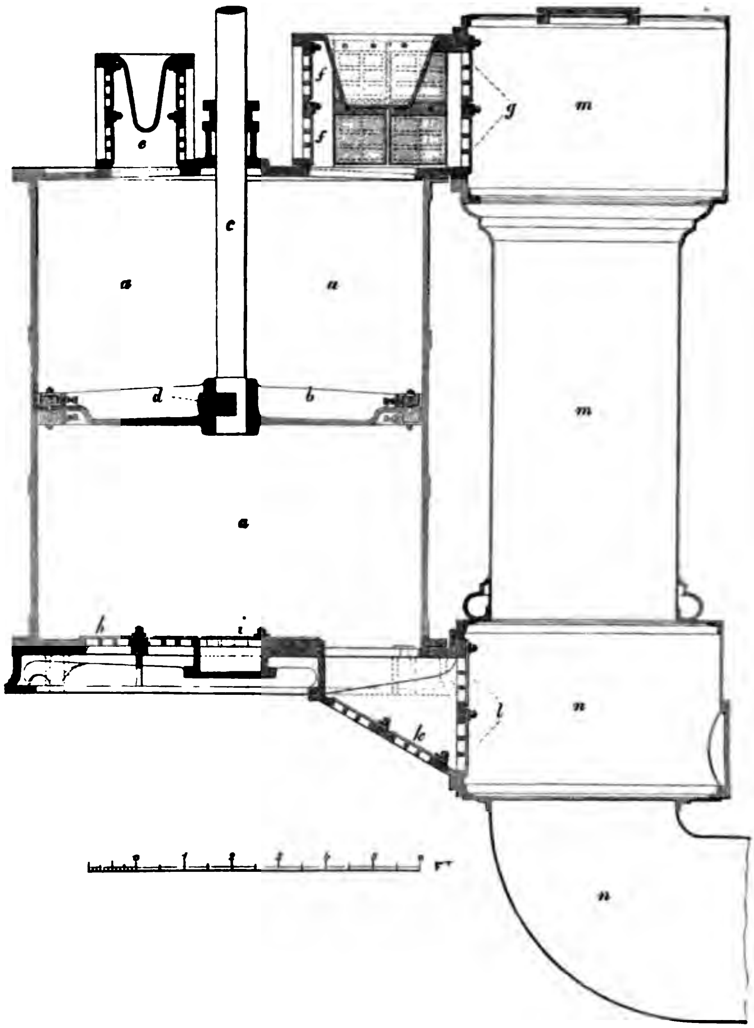


Fig. 57. Section of blowing cylinder.

long and 6 ft. diameter, which, being of such large capacity, serves as a reservoir to equalize the blast. It is supported from the ground by pillars, placed at proper intervals apart.

From the main conduit, the air passes into the heating stoves,

of which there are eight (two to each blast-furnace), and which heat the air to a temperature of about 800 deg. Fahrenheit.

From the heating stoves the air is conducted to the twyers of the blast-furnaces by cast iron pipes, 10 in. and 12 in. diameter. There are 9 blast-pipes to each furnace, the orifice of each being 2½ in. diameter. Stop valves are fixed in the pipes, by which the blast can be shut off from any of the furnaces at pleasure.

The pressure of air in the reservoir is about 3 lbs. per square in. above the atmosphere. Safety valves are provided, to allow the escape of any superfluous air.

The blast-furnaces are 60 ft. in height, and 15 ft. diameter across the boshes.

The following principles will probably be of use, as applicable generally to the supply of air to smelting furnaces by piston blast engines.

The quantity of air required for any given furnace, and the pressure at which it must be delivered, are matters which must be determined by experience for the particular case; and the dimensions of the blast engine must be proportioned accordingly.

Let A represent the area of the blast cylinder, and L the length of its stroke, both in feet, and N the number of single strokes per minute. Then the quantity of air in cubic feet, at atmospheric pressure, inhaled by the cylinder per minute, will be

$$= N A L.$$

If there is more than one cylinder, let the contents of each be thus taken, and the sum of the whole be expressed by Q = quantity of air used in cubic feet per minute, measured at the atmospheric pressure, which we will represent by P lbs. per square foot.

Now the action of the machine will be first to compress this air to the pressure existing in the equalizing reservoir, and then to deliver it into this vessel, in doing which its volume will be reduced. Let therefore the pressure in the reservoir above the atmosphere, in lbs. per square foot, $=p$, the total pressure being $= P_1 = P + p$. Also let Q_1 represent the volume of air which will be supplied per minute to the reservoir at the increased pressure.

Then by Mariotte's law, assuming the temperature constant,

$$Q_1 = Q \frac{P}{P_1}$$

The next part of the process is that this air passes through a series of pipes, in the course of which, for hot-blast furnaces, it becomes heated to a high temperature. In this it will be subject to two alterations: first, the pressure will be somewhat reduced by the quantity necessary to overcome the friction along the pipes; and, secondly, the volume will be considerably augmented by the expansion from increase of temperature.

The friction along the pipes will depend on the surface of the pipes, on the velocity of passage, and on the specific gravity of the air.

The former may be easily obtained by multiplying the length of the piping by the internal perimeter. Let this surface in square feet $= f$.

The velocity of passage and the specific gravity of the air will both vary at different parts of the piping, as the air becomes heated; and in order to reduce them to simple calculation, an estimated mean value of each must be taken. Let therefore v = mean velocity in feet per second; and S the mean weight of a cubic foot of the passing air in lbs. avoirdupois. Also let a = mean sectional area of the pipe in feet, and p' = the loss of pressure due to the friction.

Then by known rules—

$$p' = \frac{fSv^2}{Ma}$$

where M is a coefficient of friction that may be taken approximately at 10,000.

Hence the pressure (total) of the air at the end of the passage, which we will call P_2, will be

$$P_2 = P_1 - p'$$

or the pressure above the atmosphere—

$$p'' = p - p'$$

Secondly, we have to find the increase of volume due to the heating. It is known that for an increase of every degree Centigrade the volume of air will increase about $\frac{1}{273}$ of its volume at 0°. If therefore Q_1 = the first volume at temperature $t°$ Cent.,[5] and Q_2 the new volume at a higher temperature T°, we shall have[6]—

$$Q_2 = Q_1 \frac{1 + 0 \cdot 00365T}{1 + 0 \cdot 00365t}$$

Arriving now at the end of the piping we have a quantity Q_2 cubic feet of air per minute at a pressure $= p''$ lbs. above the atmosphere; and this will escape through the blast pipe nozzles and twyers to supply the furnaces.

The dimensions of these nozzles must correspond to the volume and pressure of the air intended to escape by them, and the relations of their size to these data will be found as follows:—Let a = aggregate area of the nozzles, and let v_2 be the velocity of the air in feet per second passing out by them; then the quantity escaping per minute (which must $= Q_2$) will be

$$= 60av$$

But by the rules of pneumatics, if S″ = weight of a cubic foot of the air, p'' its pressure above the atmosphere, and m = the coefficient of reduction for the shape of the orifice (which we may take for conical tubes at 0·94), we have

$$v = m\sqrt{\frac{2gp''}{S''}}$$

whence

$$Q_2 = 60am\sqrt{\frac{2gp''}{S''}}$$

[5] We adhere to the Centigrade notation in preference to Fahrenheit's, as much more convenient for calculation.

[6] The volume will also be a little affected by the diminution of pressure by the friction, but this may be neglected, being small in amount.

To find the value of S″, let W = weight of a cubic foot of air at mean atmospheric pressure, = P, and at zero (Centigrade) of temperature. This may be taken at about 0·0813 lbs.

Then $$S'' = W\frac{P + p''}{P(1 + 0\cdot00365T)}$$

And by substitution—

$$a^2 = \frac{WQ_2^2(P + p'')}{7200gPp''m^2(1 + 0\cdot00365T)}$$

from which the areas of the twyers may be found.

The power necessary to work the blast cylinders may be estimated as follows:—

If as before A = area of cylinder, L = length of stroke, P = atmospheric pressure, and P_1 = total pressure in reservoir, then the *work* in foot-pounds necessary to produce each stroke of the cylinder will be

$$= ALP \times hyp\ \log.\ \frac{P_1}{P}$$

and if N = number of single strokes per minute, then the net useful *horse-power* of the engine required will be

$$H.P. = \frac{NALP \log.\ \frac{P_1}{P}}{33,000}$$

It must be borne in mind that no allowance has been made in the above calculations for leakage, or clearance, or any mechanical defects of the apparatus; nor, in regard to the engine power, for the friction of the machinery, or other losses usual in steam engines—these will always exist to a greater or less extent; but their amount is very variable in different cases, and must be always determined by practical estimation.

As an example of the application of the principles above stated, we may give the calculations for the Shelton Company's Blowing Engines.

The blast cylinders are 100 in. diameter, working with a 9 ft. stroke, and making (when 4 furnaces are being supplied) 32 single strokes per minute. Hence,

$$\begin{aligned} A &= 54\cdot5 \text{ ft. nearly,} \\ L &= 9 \\ N &= 32 \\ \text{Or} \qquad NAL &= 15{,}700 \text{ nearly.} \end{aligned}$$

But there are two engines working together; whence,

Q = quantity of atmospheric air inhaled per minute—

$$= 31{,}400 \text{ cubic ft.}$$

or 7850 cubic ft. per minute for each blast-furnace.

This air is compressed by the blowing cylinders to a pressure of 3 lbs. per square inch above the atmosphere, and taking the atmospheric pressure at 15 lbs. per square inch, we shall have

$$\begin{aligned} P &= 2160 \\ p &= \ \ 432 \\ \text{and } P_1 = P + p &= 2592 \end{aligned}$$

And by this increase of pressure the volume supplied by the cylinders will be reduced to

$$Q_1 = Q \frac{P}{P_1} = 26{,}166.$$

We have next to find the changes of pressure and volume that the air takes in travelling through the pipes between the blowing cylinders and the furnaces, during part of which passage it is raised considerably in temperature.

The change of pressure will be due to the friction of the air in passing along the pipes; but in the case in question these passages are made so large and ample that no important diminution is found to take place, so that we may assume—

$$p' = 0 \text{; or}$$
$$P_2 = P_1 = 2592$$

Or

$$p'' = p. = 432.$$

The other alterations, however—namely, the increase in volume due to the heating, will be considerable. We have at first a volume

$$= 26166$$

at a temperature $= t$, which we may take, for the sake of example, at about the mean temperature of the atmosphere, say $= 16°$ Cent. This is heated to a temperature T = about 800° Fah. or 426° Cent., which will augment it to a volume,

$$Q_2 = Q_1 \frac{1 + 0{\cdot}00365T}{1 + 0{\cdot}00365t}$$

$$= 26{,}166 \frac{2{\cdot}555}{1{\cdot}058} = 63{,}163 \text{ cubic ft. per minute,}$$

which is the volume passing into the furnaces through the twyers.

By the equation we have before given, the quantity $a =$ the aggregate opening of the nozzles of the blast-pipes, necessary to emit this quantity at the given pressure, will be about 1·312 square ft.; and this divided over 36 blast-pipes will give about 2·6 in. calculated diameter to each, the actual diameter being 2½ in.

To find the horse power of the engines we have to calculate by the equation—

$$\text{H.P.} = \frac{\text{NALP log. } \frac{P_1}{P}}{33{,}000}$$

=186 H. P. for each engine, or 372 for the two engines together.

This is the *net* available work done; but to this has to be added a considerable allowance for friction, and other losses well known to engineers.

HOT-BLAST.

In 1828 a patent was granted to Mr. James Beaumont Neilson, manager of the Gas-works of Glasgow, with the title, 'Improved Application of Air to produce Heat in Fires, Forges, and Furnaces, where Bellows or other Blowing Apparatus are required.'[7] The specification

[7] A.D. 1828. No. 5701. Enrolled March 3rd.

of this patent occupies about three-quarters of a page, and on account of the vast importance of the application described in it I present it *in extenso*:—"A blast or current of air must be produced by bellows or other blowing apparatus in the ordinary way, to which mode of producing the blast or current of air this patent is not intended to extend. The blast or current of air so produced is to be passed from the bellows or blowing apparatus into an air-vessel or receptacle, made sufficiently strong to endure the blast, and through and from that vessel or receptacle by means of a tube, pipe, or aperture, into the fire, forge, or furnace. The air-vessel or receptacle must be air-tight, or nearly so, except the apertures for the admission and emission of the air; and at the commencement and during the continuance of the blast it must be kept artificially heated to a considerable temperature. It is better that the temperature be kept to a red heat, or nearly so; but so high a temperature is not absolutely necessary to produce a beneficial effect. The air-vessel or receptacle may be conveniently made of iron; but as the effect does not depend upon the nature of the material, other metals or convenient materials may be used. The size of the air-vessel must depend upon the blast, and on the heat necessary to be produced. For an ordinary smith's fire or forge, an air-vessel or receptacle capable of containing twelve hundred cubic inches will be of proper dimensions; and for a cupola of the usual size for cast-ironfounders, an air-vessel capable of containing ten thousand cubic inches will be of a proper size. For fires, forges, or furnaces upon a greater scale, such as blast-furnaces for smelting iron, and large cast-ironfounders' cupolas, air-vessels of proportionably increased dimensions and numbers are to be employed. The form or shape of the vessel or receptacle is immaterial to the effect, and may be adapted to the local circumstances or situation. The air-vessel may generally be conveniently heated by a fire distinct from the fire to be effected [*sic*] by the blast or current of air; and generally it will be better that the air-vessel and the fire by which it is heated should be inclosed in brickwork or masonry, through which the pipes or tubes connected with the air-vessel should pass. The manner of applying the heat to the air-vessel is, however, immaterial to the effect, if it be kept at a proper temperature."

The patentee, there is reason to believe, had at first no adequate conception of the value of his invention, and of the great influence it was destined to produce upon the smelting of iron. The particular reference which he makes in his specification to smiths' fires and cast-ironfounders' cupolas would seem to indicate that he regarded his invention as more specially applicable to these minor operations than to great blast-furnaces. The advantages, however, of the hot-blast, with respect to economy of fuel, were so soon recognized by the Scotch ironmasters that in 1835 it was in operation at every ironwork in Scotland, except one, and there it was in process of introduction.

In 1832, Mr. Neilson and others, with whom he had entered into partnership with respect to his invention, granted a licence to the well-known ironmasters, Messrs. Baird, proprietors of the Garthsherry Ironworks, on consideration of receiving one shilling per ton of iron manu-

factured at their establishment. These gentlemen subsequently refused to pay the licence-duty, whereupon legal proceedings were instituted against them by Mr. Neilson. At the date of the action 20,000*l.* were claimed by the plaintiffs, of which half was for "profits" and half for "other damages." The litigation was, as usual in such cases, both costly and fierce. The defendants endeavoured to upset the patent on various pleas, especially insufficient description and want of novelty. The trial took place at Edinburgh in 1843, before the Lord President of the Court of Session, and lasted from the 10th to the 20th May inclusive. Witnesses were summoned from all parts of the kingdom, and there was not a little hard and contradictory swearing. In proof of non-novelty, great stress was laid on the specification of a patent of a Mr. Robert Stirling, dated 1816, and numerous extracts from it were presented to the Court. This specification has not been printed, nor is there any record of it in the library of the Patent Office, where, at my request, diligent search has been made for it. The judge summed up strongly in favour of the plaintiffs on all the issues, and the jury returned a verdict in their favour accordingly, assessing the damages for "profits" at 4867*l.* 16*s.*, and the "other damages" at 7000*l.*

Counsel resorted to much severity of language, both in their cross-examination and in their addresses to the jury; and so did the Lord President in his summing up. Much of the evidence is highly discreditable and disingenuous. Opinions were expressed by some of the witnesses which have proved utterly erroneous, and which no doubt they would be glad to have the opportunity of disavowing. As an example may be cited one of the answers of Mr. James Palmer Budd, of the Ystalyfera Iron-works, which is as follows:—"I find that the cold-blast is most economical; it produces more iron at less expense of wages and material." Yet Mr. Budd afterwards adopted the hot-blast at his own furnaces. The defendants admitted that during 10 years they made 260,000*l.* net profit on hot-blast iron, and that in one year (1840) the net profit amounted to 54,000*l.* One might naturally have supposed that this splendid return would have satisfied their cupidity, and that they, of all men, would have been the last to attempt to dispossess Neilson of his patent right; but so it is, so it has always been, and so, it is to be feared, it ever will be, in accordance with the proverb, "Much would have more."[a]

The late Mr. Mushet gave evidence at the trial, and declared that in his opinion the invention of the hot-blast, considered as a means of developing national wealth, might properly rank with that of cotton-

[a] A complete report of this remarkable trial was printed in Edinburgh. The title is "Report of the Trial before the Lord President of the Court of Session and a Special Jury, of the issues in the conjoined actions of Suspension and Interdict, and Count, Reckoning, Payment, and Damages, at the instance of James Beaumont Neilson, of Glasgow, Engineer, and others, against William Baird and Company, of the Garthsherry Iron-Works, for infringement of the Hot-Blast patent; commencing on 10th, and ending on 20th May, 1843. Edinburgh: printed by Thomas Allan and Co., 265, High Street, 1843." 4to. pp. 331.

spinning by Arkwright. However this may be, few persons would now demur to the statement that the hot-blast has greatly cheapened the production of iron, and in so far is to be regarded as one of the most important improvements ever made in metallurgy. It cannot strictly be termed a great invention; for what great exercise of the inventive faculty could it possibly have required for its development? There was no elaborate working out of a process or machine, as has been the case in many inventions, but the thing was done at once. Without wishing in the smallest degree to detract from the merit to which Mr. Neilson is justly entitled, I may nevertheless express my opinion that the hot-blast was a lucky hit rather than an invention properly so called. Yet it should not be forgotten that before Mr. Neilson appeared on the scene it was a conviction of ironmasters that the colder the blast the better. "This conviction," as Mr. Marten observes, "was the result of long-continued observations, which showed that the produce per furnace was always more in winter than in summer; and as the difference most appreciable to the furnace-managers between the one state of circumstances and the other was the temperature of the atmosphere, this, without further investigation, was at once charged as the sole cause. Subsequent research has shown that the mere variation of temperature in the atmosphere, from freezing-point to summer-heat, had nothing to do with this result, which is owing to a cause still as actively in operation, and as sensibly felt with the blast heated to a temperature of 600° or 800° F., namely the excess of moisture, in the shape of invisible vapour, contained in the air in the warm weather as compared with the cold. So strongly rooted, however, was the belief that the temperature was the only circumstance affecting the make of iron, that the greatest efforts were made in summer to obtain the blast as cool as possible; amongst other plans, by passing it over cold water, with a result of course contrary to expectation, owing to a partial absorption of the water."[a]

With respect to variation in atmospheric temperature, there is one point deserving of notice which is not alluded to by Mr. Marten, namely, that in hot weather the blowing engine, in order to inject the same weight of oxygen, in a given time, into the furnace as in cold weather, must work more rapidly; and it is possible that furnace-managers may have neglected so to increase the speed of the engine as to compensate for the effect due to the variation in temperature during the hot season. And if this be so, they may have been led to the inference above stated, that the increased temperature of the blast at this period of the year was injurious. However, the greater humidity of the air in hot weather would no doubt tend to produce the effect alleged by Mr. Marten; but he now doubts whether it is so exclusively operative as he then supposed.

The hot-blast was first put into operation at the Clyde Iron-works,

[a] On the Construction of Hot-Blast Ovens for Iron Furnaces. By Mr. Henry Marten, of Wolverhampton. Proceedings of the Institution of Mechanical Engineers, May 4th, 1859, p. 62. This is an excellent paper, of which I shall largely avail myself.

where argillaceous iron-ore was smelted with limestone as the flux, and with the coke of splint-coal (*i. e.* bituminous non-caking coal rich in oxygen, yielding 45$^\circ/_0$ of coke) as the fuel.[1] During the first 6 months of the year 1829, when cold-blast was exclusively used at the Clyde Iron-works, the coke from 8 tons 1¼ cwt. of coal was required to produce 1 ton of pig-iron. During the first 6 months of the following year, when the blast was heated to 300° F., 1 ton of pig-iron was obtained with a consumption of the coke from 5 tons 3¼ cwts. of coal. The actual saving of coal per ton of pig-iron was 2½ tons, as 8 cwts. of coal were consumed in heating the blast, and must be deducted from the saving of 2 tons 18 cwts. in the blast-furnace.

In 1831, at the Calder Iron-works, raw coal was successfully substituted for coke; and this use of raw coal was speedily adopted in most of the Scotch iron-works. The temperature of the blast was raised sufficiently high to melt lead, and sometimes even zinc; and the use of water-twyers had become necessary.

During the first 6 months of the year 1833, at the Clyde Iron-works, under the altered conditions just stated, 1 ton of pig-iron was made with 2 tons 5¼ cwts. of coal used raw, exclusive of 8 cwts. required to heat the blast. The actual consumption of coal therefore was 2 tons 13¼ cwts., whereas in 1829 it was 8 tons 1¼ cwt. per ton of pig-iron.

The results obtained at the Clyde Iron-works, with regard to make of pig-iron and consumption of fuel, during the three periods above referred to (the blowing engine being the same), are given in the Table subjoined:—

Coke and Cold-Blast. From Jan. 7th to Aug. 19th, 1829.		Coke and Hot-Blast. From Jan. 6th to June 30th, 1830.		Coal and Hot-Blast. From Jan. 9th to June 30th, 1833.	
Average weekly make of pig-iron in three furnaces.	Average consumption of coal per ton of pig-iron.	Average weekly make of pig-iron in three furnaces.	Average consumption of coal per ton of pig-iron.	Average weekly make of pig-iron in four furnaces.	Average consumption of coal per ton of pig-iron.
Tons. Cwts. Qrs.	Tons. Cwts. Qrs.	Tons. Cwts. Qrs.	Tons. Cwts. Qrs.	Tons. Cwts. Qrs.	Tons. Cwts. Qrs.
110 14 2	8 1 1	162 2 2	5 3 1	245 0 0	2 5 1

Hence, by the application of the hot-blast, the same amount of fuel reduced three times as much iron, and the same amount of blast did twice as much work, as previously.[2] In reference to the consumption of coal, it is essential to bear in mind the composition of the coal; for otherwise no really accurate comparisons can be instituted concerning the consumption of coal per ton of pig-iron in different localities, yielding varieties of coal of widely different composition. For example, the non-caking bituminous coal of Scotland and South Staffordshire contains much more oxygen and much less carbon than the non-caking

[1] A paper was read to the Royal Society of Edinburgh, March 16th, 1835, by Dr. Clark, Professor of Chemistry at Aberdeen, "On the Application of the Hot-Blast in the Manufacture of Cast-Iron." The following information relating to the early history of the hot-blast is chiefly derived from this paper.

[2] Dr. Clark, op. cit. p. 378.

bituminous semi-anthracitic coal of South Wales; and carbon is the chief calorific agent in both. But this consideration, which is of great practical importance, is often disregarded in comparative statements as to the consumption of coal per ton of pig-iron, at iron-works supplied with different kinds of coal.

At the Clyde Iron-works the blowing engine had a steam cylinder 40 in. in diameter, and a blowing cylinder 8 ft. deep and 80 in. in diameter, making 18 strokes a minute. The whole power of the engine was exerted in blowing the three furnaces, as well as in blowing the four; and in both cases there were two twyers of 3 in. in diameter to each furnace. The pressure of the blast was 2½ lbs. per square inch. The fourth furnace was blown in after the introduction of water-twyers, and the open spaces round the blast-pipes were luted up. The engine then went less than 18 strokes a minute, in consequence of the too great resistance of the materials contained in the three furnaces to the blast in its passage upwards. The charge, in 1829, consisted of coke 5 cwts., calcined ironstone 3 cwts. 1 qr. 14 lbs., and limestone 3 qrs. 16 lbs.; in 1830, of coke 5 cwts., calcined ironstone 5 cwts., and limestone 1 cwt. 1 qr. 16 lbs.; and in 1833, of coal 5 cwts., calcined ironstone 5 cwts., and limestone 1 cwt.[3]

Apparatus for Heating the Blast.

Human ingenuity has been exercised in a remarkable degree upon modes of heating the blast, and very numerous kinds, or rather varieties, of apparatus have been contrived for that purpose, and tested on the large scale. To describe them all would require a volume; and I shall therefore select for special description only such as are more or less typical, and these are but few. The best account which I have met with of British hot-blast ovens is that of Mr. Marten, previously cited. An important German work on this subject, by Mehrbach, illustrated with admirable plates, was published so long ago as 1840.[4] It records many contrivances of at least historical interest, to which Mr. Marten does not allude; but it is now necessarily very imperfect.

Neilson's first apparatus.—The apparatus first employed by Mr. Neilson was exceedingly simple. It consisted of a small wrought iron heating chamber, about 4 ft. long, 3 ft. high, and 2 ft. wide, similar in construction to a waggon-head steam-boiler, and set in brickwork with a fire-place underneath, the top being left exposed to the atmosphere.[5] The cold-blast entered at the end immediately over the grate, and passed out from the opposite end direct into the twyer, at a temperature of about 200° F. Each twyer was provided with one such

[3] Dr. Clark, op. cit. p. 382.

[4] There is one volume of text with the following title: "Die Anwendung der erwärmten Gebläseluft im Gebiete der Metallurgie." Herausgegeben von F. Th. Mehrbach. Leipzig, 1840. 8vo. pp. 365. There is an atlas of 35 folio plates, which was published at Freiberg, in 1840. The title is as follows: "XXXV. Tafeln Abbildungen der vorzüglichsten Apparate zur Erwärmung der Gebläseluft auf den Hüttenwerken in Deutschland, England, Frankreich, Schweden und der Schweiz. Freiberg, 1840." It is a posthumous publication.

[5] Marten, op. cit. p. 63.

heating chamber. The total area of fire-grate per twyer was about 4 ft. square, and that of the heating surface of the chamber 35 ft. square. The advantage of heating the blast even to this moderate degree was soon established.

Neilson's improved apparatus.—The chamber being made of boiler-plate was speedily destroyed by oxidation, when Mr. Neilson substituted for it a cylindrical vessel of cast iron, bottle-shaped at each end, 2 ft. 9 in. in diameter, and 6 ft. in length. It was fixed horizontally over a fire-place, and wholly enclosed in brickwork, thus avoiding the great loss of heat by radiation, etc., which occurred in the first apparatus. The area of the grate was 11 ft. square, and the heating surface for the blast 55 ft. square. An apparatus of this kind was adjusted to each twyer. The temperature of the blast was now raised to 280° F.

Mr. Neilson next contrived a far more efficient apparatus than the two preceding, by which the temperature of the blast was raised to more than 600° F., so that lead could easily be melted by it. It consisted of an arrangement of cylindrical cast-iron pipes, 18 in. in diameter, fixed horizontally and united by flanges. These pipes together formed a continuous length of 100 ft., and presented a heating surface of 240 ft. square for each twyer. There were five grates in all, giving 28 ft. square of grate surface for each of the two twyers. In this apparatus hot-blast, properly so called, was first produced; but, as Mr. Marten remarks, "defects soon began to manifest themselves. With the lengthening of the heating tubes and the greater general complication of the apparatus, a difficulty had now crept in unawares, destined to be highly mischievous, and to test the ingenuity of a whole generation of furnace managers. It arose from irregular and uncompensated expansion and contraction, inducing that serious defect of hot-blast ovens, leaky joints. . . . . . The leakage at the joints was to some extent overcome by covering them with a ring of cast-iron, followed as a result by the breaking of the pipes, a defect of greater magnitude."[6] But the greatly increased yield of the furnace, consequent on the higher temperature of the blast, led to strenuous efforts to overcome the difficulty.

The defects of the apparatus in question may, as Mr. Marten has shown, be summed up as follows: 1. The heating of so great a continuous length of piping, whereby the effect of the accumulated expansion of the several straight pipes would be concentrated on the weakest point in the system; and, moreover, owing to the mode of heating, there would be necessarily irregularity in the expansion and contraction, and the piping in the immediate vicinity of the fire-places would be more heated at one time than elsewhere, and more cooled at another when the fires were made up. 2. The difficulty, not to say impossibility, of keeping the flanged joints tight under the circumstances; for, in consequence of the great and repeated strains to which the pipes were subjected from variations in temperature, the cement between the flanges was ground to powder and dropped out.

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[6] Marten, op. cit. p. 65.

At length, what is called "the cast-iron tubular oven" was invented by Mr. Neilson, and of this all subsequent improvements may be regarded merely as modifications. This apparatus consists essentially of two large cylindrical cast-iron pipes or mains, placed horizontally, parallel to, and at a certain distance from, each other. These mains are connected together by a series of smaller cylindrical cast-iron pipes, curved semicircularly, and fixed vertically like syphons, with the convexity upwards. The ends of these so-called arch-pipes fit into socket openings in the upper surface of the mains respectively. Between the mains is a fire-place, of which the grate extends under about half the vertical arch-pipes. On each side of the fire-place the mains are imbedded in brickwork, the sockets only being left free at the top. The system of arch-pipes is enclosed within a semicircular arch of brickwork, having a flue at the top connected with a chimney. Space is left between the internal surface of this brick covering and the arch-pipes, in order that these may be everywhere fully exposed to the action of the flame or heated products of combustion of the fuel. The blast from the blowing engine entered one of the mains, and passed through the arch-pipes into the other main, from which it was conducted in a highly heated state to the twyer. Three twyers were now employed, and each, as heretofore, had its own hot-blast oven. The dimensions of such an oven were as follow :—

Diameter of the mains	12 in.
Length of each main	10 ft.
Distance between the mains, from centre to centre	6 ft.
Number of arch-pipes	9.
Internal diameter of arch-pipes	4 in.
External diameter of arch-pipes	7 in.
Height from grate to underside of arch-pipes	4 ft. 4 in.
Area of heating surface per twyer	150 ft. square.
Area of fire-grate per twyer	15 ft. square.

In this oven the blast was heated to as high a temperature as in that last described, with less than two-thirds of heating surface per twyer, and with little more than half the grate area; and there was also a smaller consumption of fuel, less leakage, and greater regularity of action. The irregularity of action occasioned by firing was much diminished, as each oven had its own independent grate, and the evil of flange joints was avoided.[7]

Notwithstanding this last decided advance in the way of improvement, it soon became apparent that many defects yet remained. The socket joints would still occasionally leak, however hard the cement might be rammed in; the arch-pipes would crack; there was danger of overheating these pipes from carelessness in firing, and of "burning down the whole apparatus when the fire was at all hastened, a case which happened once or twice;" the temperature of the blast could not long be maintained at 600° F. without great damage to the arch-pipes; the pressure of the blast was seriously reduced by friction in its course through these pipes; and "owing to the proximity of the oven

[7] Marten, op. cit. p. 67.

to the twyer-house," it was difficult properly to attend to the twyers, especially in summer, when the workmen were literally roasted, by being "hemmed in on one side by the hot ashes from the furnace on drawing the twyer, and on the other by the oven."[8]

Syphon pipe oven.—In order to provide against the evil of overheating, the arch-pipes were elongated into syphon-shaped pipes, and the oven was heated by the flame and products of combustion from a separate and adjoining fire-place. The legs, if I may so call them, of each pipe approximated closely at the top, and were much wider apart at the bottom or their socket ends. It is stated that an oven of this construction was erected by Messrs. Firmstone, at the Lays Iron-works, near Dudley, and that the same plan was put into operation by Mr. Neilson at the Calder Iron-works and elsewhere.[9] One of these ovens sufficed to heat the blast for three twyers at the temperature of 600° F. The dimensions of Messrs. Firmstones' oven were as under:—

Length of horizontal mains	7 ft. 6 in.
Number of syphon pipes	9.
Area of direct heating surface, total	240 ft. square.
Do. do. per twyer	80 ft. square.
Area of fire-grate, total	9 ft. square.
Do. per twyer	3 ft. square.

This kind of oven was extensively adopted, and answered well; but fracture of the syphon pipes and leakage of joints still continued, though to a less extent than previously. The syphon pipes in Messrs. Firmstones' oven were not circular, but oval in bore. This form, it is evident, presents a greater heating surface for a given volume of blast than a circular one, and in so far is an improvement.

Mr. Marten specifies the following dimensions for what he terms the "improved Staffordshire oven:"—

Length inside casing (*i.e.* of brickwork)	16 ft.
Breadth do.	7 ft. 6 in.
Number of syphon pipes	16.
Area of heating surface, total	700 ft. square.
Do. do. per twyer	175 ft. square.
Area of fire-grate, total	35 ft. square.
Do. per twyer	9 ft. square.

The legs of the pipes are cast thicker on the inside, where they are exposed to the strongest heat. By means of a stop in the centre of the influx main, the blast passes up half of the series of syphon pipes into the opposite main, and from thence up the other half of this series back into the corresponding half of the first main, from which it is conveyed to the twyers. An oven of the above description may virtually be regarded as consisting of two ovens, joined, as it is termed, "end on."

The cracking of the pipes, previously adverted to, in ovens with fixed mains occurs chiefly at the top or convex side, and the cause, which now seems obvious enough, was not discovered for a considerable time. As the legs of the syphon pipes are set in these fixed mains,

[8] Marten, op. cit. p. 68. [9] Ibid. p. 69.

they cannot, when heated even to the same degree, expand equally above and below.

In consequence of this, they would tend to become more divergent upwards, and necessarily be liable to crack at the convexity. This defect was subsequently remedied to a certain extent by supporting one of the mains on cast-iron saddles or rollers, whereby it acquired freedom of motion, so as to allow the legs of the pipes to expand below as well as above. Spherical balls of cast-iron have been successfully employed for this purpose. It is found that with such an arrangement the loose main changed its position to the extent even of 2 in.; and, accordingly, advantage has been taken of this to construct a pyrometer, whereby the temperature of the blast may be at all times approximately known, without the necessity of resorting to the rough and common practice of making a special experiment to ascertain whether it will melt lead. The pyrometric apparatus required is of the simplest kind, and is sufficiently exact for practical purposes. It is fixed outside the oven, and consists of an index or lever, working on a horizontal axis, one arm being very short and attached to the outer side of the main. Any motion, therefore, communicated to this arm by a change of position in the main will be rendered extremely sensible by the motion of the point of the long arm or index. Experiments will be needed at first to determine the temperatures corresponding to the position of the index. In reference to the subject of pyrometers, Mr. Marten has expressed to me his high opinion of those made by Gauntlett, of Middlesboro'-on-Tees, which are constructed on the principle of the differential expansion of rods or tubes of brass and iron. He has used them for nearly six years, and found them for all practical purposes apparently as good as new.

Attempts have been made to communicate the motion of the loose main to the dampers of the oven by lever arrangements, so that the temperature of the oven may be thereby regulated. The mechanism adapted for this object would naturally suggest itself to any person of ordinary mechanical skill.

But the remedy adopted to counteract the evil due to fixed mains created another evil; and now it was found that, although fractures were less frequent than previously, yet they nevertheless occurred; not on the convex side, as before, but on the concave or under side. According to Mr. Marten, "this was accounted for by the fact that the strain in pushing out the loose main was comparatively easy to be borne, being distributed over the long bend of the top side of the crown; but the underside of the bend was of the weakest form for pulling back the heavy loose main on a reduction of temperature, especially when the rollers had become clogged with an accumulation of indurated dust and clinker, as was frequently the case."[1]

In order to obviate this new defect the loose main was abandoned, and the legs of the syphon pipes were made parallel, and not convergent upwards, the curve at the top being semicircular. The section of these pipes was a long rectangle with the angles rounded off,

[1] Marten, op. cit. p. 78.

thus forming, as it were, a flattened ellipse. They are set in the mains with their narrow sides towards the fire. These pipes are stated to answer admirably, and they are not apt to crack in any part of the semicircular arch, the strain on expansion being distributed over such a length of circumference as to enable the metal to stand.[2]

I present engravings of a double syphon pipe oven, erected at the New British Iron Company's Works, Corngreaves, by Mr. Kenyon Blackwell, to whom I am indebted for the drawings from which these engravings have been executed. It is fired with coal, and is reported to work extremely well in every respect. Each of the mains, it will be perceived, is moveable on cast-iron balls placed underneath. Details of every part of the oven will be found in the accompanying engravings, figs. 58 to 62 inclusive, which, it is apprehended, will be sufficiently intelligible without further description.

Box-foot pipe oven.—The horizontal mains are replaced by a continuous series of cast-iron boxes, each of which has two sockets on the top. The heating pipes are syphon shaped, with parallel instead of diverging legs. They are set vertically, or, as it is termed, footed, in the sockets of the cast-iron boxes abovementioned, the legs of each pipe fitting into the respective sockets of two contiguous boxes. The blast passed up one leg of a pipe and down the other, and so on consecutively through the system. I saw this arrangement at the Ystalyfera furnaces in 1848; the ovens were heated by the waste gas of the furnaces, as previously described. Ovens of the same construction were erected in North Staffordshire. According to Mr. Marten, the friction proved to be so great as considerably to reduce the pressure of the blast, and in consequence they were never extensively adopted.

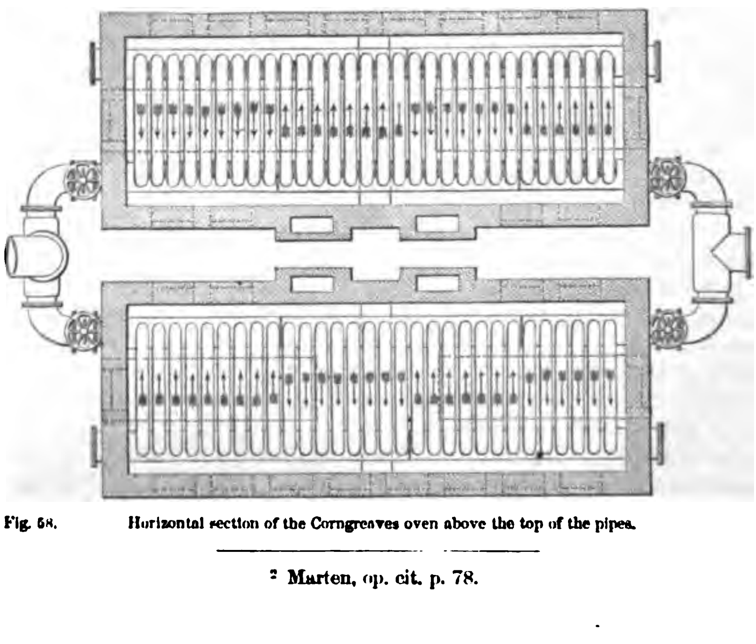


Fig. 58. Horizontal section of the Corngreaves oven above the top of the pipes.

[2] Marten, op. cit. p. 78.

Spiral-pipe oven.—The apparatus consists of a long spiral of cast-iron pipes, circular in bore, connected with each other by cemented socket joints, fixed with the axis horizontal, and sufficient space being left between the coils to allow of their being uniformly heated. The waste gas of the blast-furnace is used as the fuel. I have seen this arrangement in operation at the Ebbw Vale Iron-works, and my friend, Mr. Adams, the manager, informed me that it worked well, heating the blast regularly, but occupied much space, which is not a matter of consideration at many iron-works. As, however, the blast has to

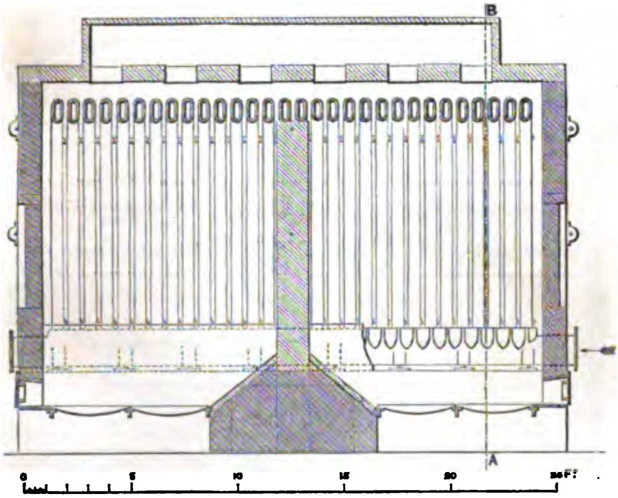


Fig. 59. Longitudinal section of the Corngreaves oven through centre looking outwards.

travel at a high velocity through one continuous pipe, there must necessarily be a considerable amount of friction, notwithstanding the absence of angles, etc.

Ovens having a spiral pipe fixed with the axis vertical have also been tried, and, I believe, with favourable results. In such an arrangement it is obviously necessary to interpose adequate supports between the coils.

Pipe-within-pipe oven.[3] — The apparatus consists of two straight cast-iron pipes, circular in bore, fixed horizontally one above the other, each being enclosed within a distinct brick chamber, and with a fireplace under the lower pipe, but separated from it by an arched roof

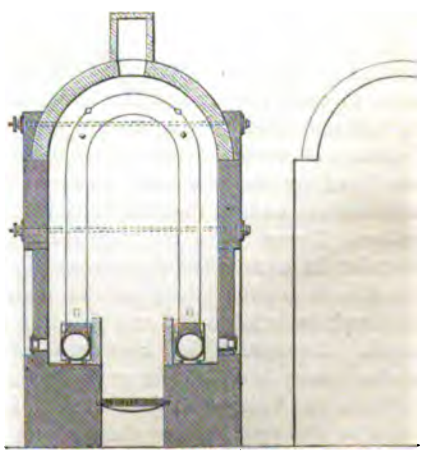


Fig. 60. Cross section on the line A B, fig. 59.

[3] Mehrbach, Plate XIV.

with a succession of openings in it to serve as flues. These pipes were connected together at one end, and contained another system of cast-iron pipes also circular in bore, placed axially, and so much less in diameter as to leave a considerable annular space between them and the outer pipes. The whole was suitably enclosed in brickwork with an arched roof. The blast entered the upper small pipe, and passed into the annular space at the opposite end, whence it proceeded

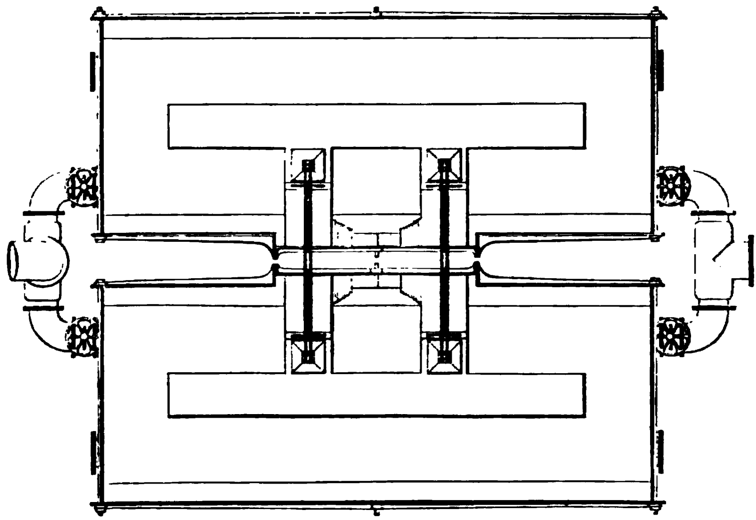


Fig. 61. Plan of top of a pair of the Corngreaves ovens.

into the lower small pipe, and, similarly, at the other end entered the second annular space, finally escaping through a contracted opening into a twyer. An oven on this principle was erected at the Codnor Park Iron-works, Derbyshire, in 1836. The evil of flanged joints existed in this oven, and the friction was great. There was one such oven to each twyer, and the temperature of the blast was lower than in Neilson's oven with arched pipes.[4]

Oven with vertical horse-shoe shaped mains.—At each end of the oven was fixed vertically a cast-iron main, circular in bore and curved like a horseshoe, except that the legs were parallel and did not converge below. These were connected by a series of cast-iron pipes, also circular in bore, placed horizontally and parallel to each other, and fitted into socket joints in the mains. The whole, of course, was enclosed in brickwork, and the fire-place was at one end, not underneath. An oven of this kind was constructed at the Monkland Iron-works, near Airdrie. It proved a comparative failure, and it was liable to the "serious objection that, in the event of one pipe becoming burnt or damaged, either the sockets must be stopped up at each end,

[4] Marten, op. cit. p. 71.

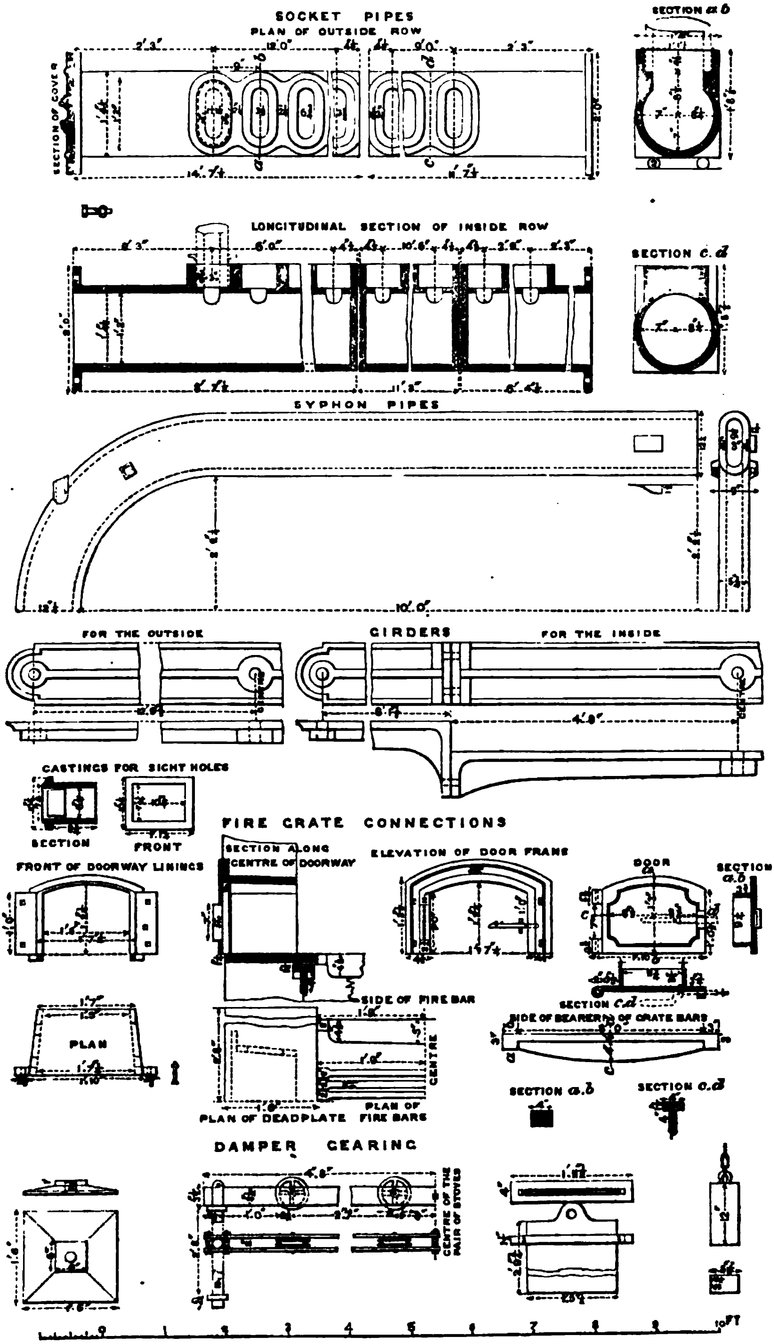


Fig. 62. Details of the Corngreaves ovens.

or the whole apparatus taken down to insert a single new pipe.[5] Interest, however, attaches to this oven, as it is stated to have been the first in which a curved main was employed.

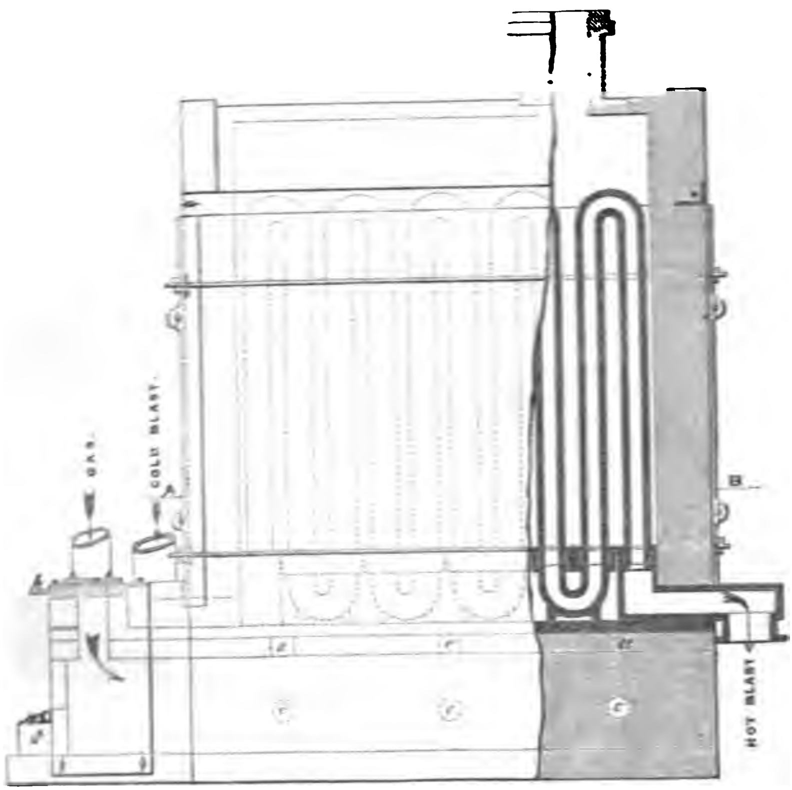


Fig. 63. Side elevation in partial section of the Blaina oven.

Gas-oven.—The waste gas of the blast-furnaces is employed as fuel. The oven which I have selected for description is one of those in operation at the Blaina Iron-works, and for drawings of which I am indebted to my friend, Mr. Levick. It is represented in the accompanying engravings. Fig. 63, side-elevation, showing partial vertical section of the interior on the median line. Fig. 64 *b*, horizontal section on the line A B, fig. 63. Fig. 64, end elevation. Fig. 64 *a*, vertical cross section. It consists of a rectangular brick chamber, of which the walls are vertical for a short distance from the floor, and then incline slightly inwards to the top (see fig. 64 *a*, *d*, *d*), where they are covered in by an arched roof, in which is a very low chimney. The lower part of

[5] Marten, op. cit. p. 71.

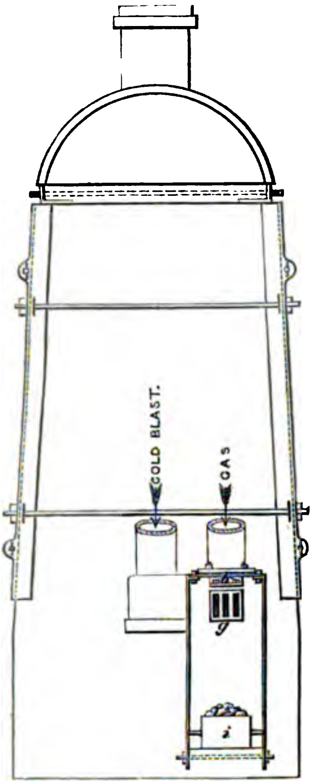


Fig. 64. Front end elevation of the Blaina oven.

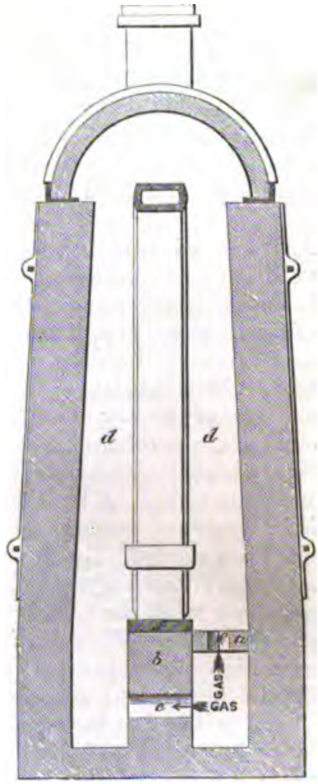


Fig. 64a. Vertical cross section of the Blaina oven.

this chamber is divided longitudinally by the wall, *b*, into two equal spaces. One of these spaces is covered at the top by a flat wall of fire slabs *a*, while the other space is left open. In the wall *a*, are three circular openings *e*, *e*, *e*; and in the wall *b*, there are also three

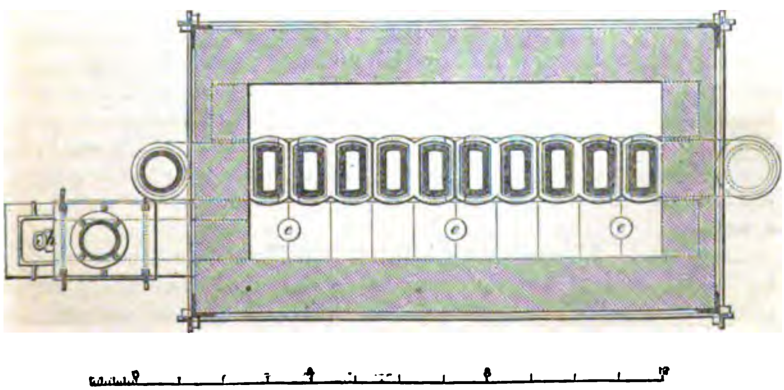


Fig. 64*b*. Horizontal section of Blaina oven on the line A B, fig. 63.

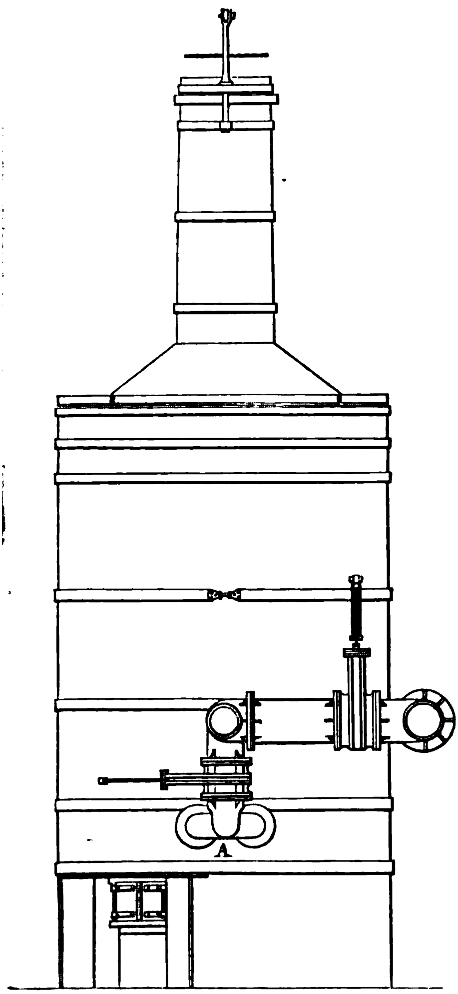
similar and corresponding openings *c*, *c*, *c*. The hot-blast apparatus consists of a single row of syphon-shaped cast-iron pipes, of which the bore is rectangular and the legs are vertical. The legs are fitted by socket-joints into cast-iron foot-boxes. The gas enters where indicated in figs. 63 and 64 into a small rectangular brick ante-chamber, whence it passes into the lower covered compartment of the oven on the right-hand side, and from thence partly upwards through the apertures *e*, *e*, *e*, and partly to the left through the apertures *c*, *c*, *c*, in the wall *b*. As it enters it is met by a current of atmospheric air admitted through vertical slits in the door *g*. In order to secure constant ignition, there is a small box *i*, containing burning coal, on the outside at the bottom of the ante-chamber, into which the flame of this coal passes. Immediately above the door *g*, is a horizontal slide valve *h*, by means of which the admission of the gas is regulated. Cold-blast passes into one end of the row of syphon-pipes, as shown in figs. 63 and 64, and escapes at the other end, as shown in fig. 63. The whole structure is firmly braced with castings and wrought-iron tie-rods. These stoves work admirably. A high temperature is readily obtained in them; and it is, moreover, remarkably equable in every part, and may be regulated to a nicety. The labour of stoking is avoided, and very little attention is necessary. At Blaina I observed that one old man sufficed to attend to all the hot-blast ovens. Care, however, must be taken to keep up the small fire in *i*; for, otherwise, in the event of accidental extinction of the gas, an explosion might take place on re-ignition. Special precautions are also needed in setting the oven to work. It should in the first instance be thoroughly filled with gas before the latter is ignited. If this be neglected, an explosion may result. I witnessed an explosion from this cause at the Dowlais Iron-works, of which the effect was to blow out one of the end walls of the oven.

In another of these hot-blast gas-ovens, or as they are generally termed in Wales stoves, the row of syphon-pipes was suspended from cast-iron framework at the upper part of the stove. (An engraving of this arrangement will be given hereafter under the head of Puddling.)

At Blaina and Ebbw Vale I saw the application of the waste-gas of the blast-furnaces carried out apparently to perfection. I have never witnessed any metallurgical operation with more pleasure than that of these hot-blast stoves; and I have felt no small degree of commiseration for ironmasters who still pursue the old plan of using solid fuel, such as coal-slack, however cheaply it may be obtained. Mr. Levick, of the Blaina Iron-works, assures me that the saving effected at his works by the application of the waste gas of the blast-furnaces to the heating of the hot-blast ovens and steam-boilers, is equivalent to 600 tons of coal a week.

Round oven.—All the ovens hitherto considered are rectangular in horizontal section; but that now to be described is circular; and in other respects the construction is essentially different. An oven of this kind in use at the Russell's Hall Furnaces, near Dudley, is represented in the accompanying engravings (figs. 65 to 72 inclusive), which have been executed from drawings prepared under the direc-

tion of my friend, Mr. George Shaw, of Birmingham. The main is of cast-iron, circular, and cast in two semicircular portions. It is not, as heretofore, cylindrical, but trapezoidal, the bottom, which is widest, and the top being parallel to each other. It is divided by a vertical septum along its whole course into two equal and similar spaces, *a*, *b*. On its upper and smaller parallel side are two series of socket pieces to receive the lower ends of the heating pipes, as shown in fig. 66. Each



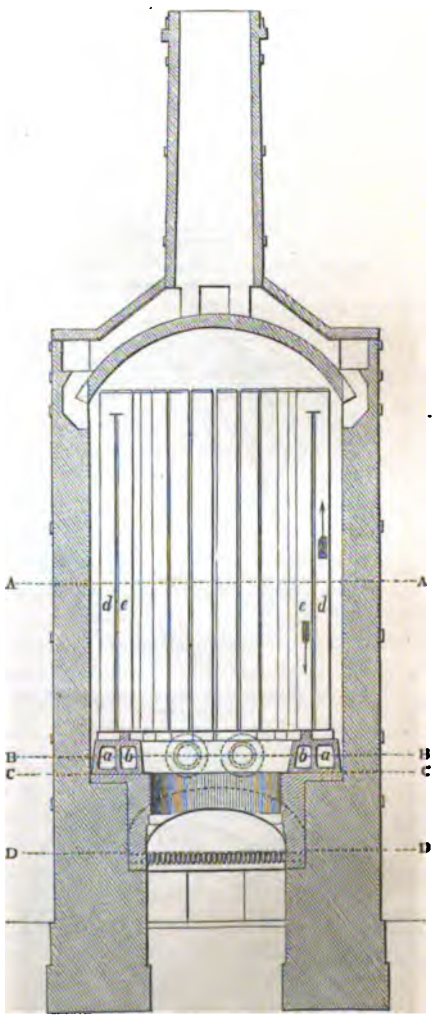


Fig. 65. Elevation of round oven.

Fig. 66. Vertical section of round oven through the centre, on the same plan as Fig. 65.

pair of heating pipes, which are of cast-iron, is cast in one piece. The main rests on a solid platform of brickwork immediately over the fire. The whole heating apparatus is enclosed within a cylindrical chamber of brickwork. The flame and products of combustion ascend through a

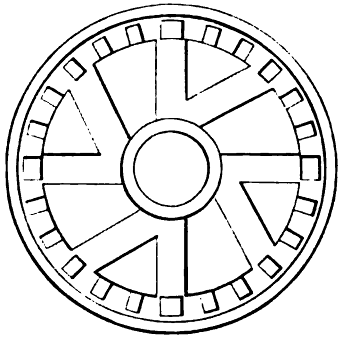


Fig. 67. Horizontal section of round oven, showing plan of the flues at the top.

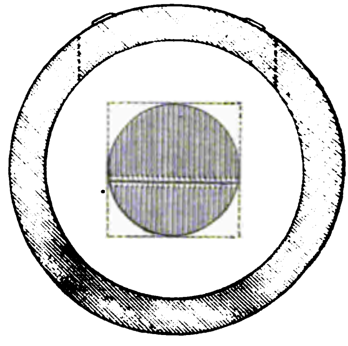


Fig. 68. Horizontal section of round oven on the line C C, Fig. 66.

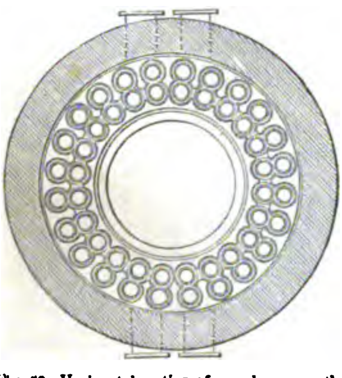


Fig. 69. Horizontal section of round oven on the line AA, Fig. 66.

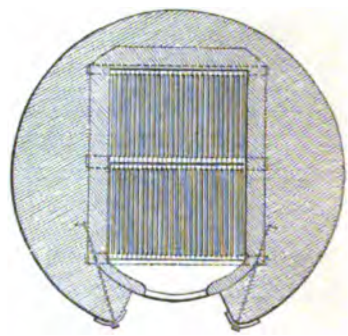


Fig. 70. Horizontal section of round oven on the line DD, Fig. 66.

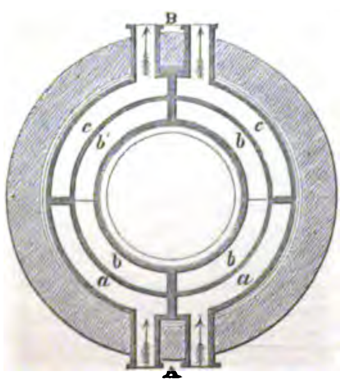


Fig. 71. Horizontal section of round oven on the line B B, Fig. 66.

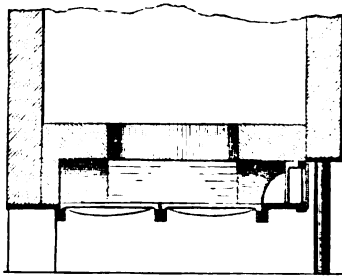


Fig. 72. Vertical section of round oven through the centre of the fire-place in the direction of the grate-bars.

circular opening, as shown in fig. 72. The central space within the pipes is left vacant. This space is covered in at the top by a brick arch, above which is a conical dome, having a short chimney at the summit. Around the circumference below the lower arch is a series of flues, communicating with the space included between the exterior of this arch and the interior of the dome: see fig. 66. Cold-blast enters where shown in figs. 65, 71, through two mouth-pieces, into the outer division of the main *a*, *a*, as far as the stops, as shown in fig. 71. It ascends through the outer pipes, and then down into one-half of the inner division of the main, fig. 71, *b*, *b*. It again ascends from the other half *b′*, *b′*, and again descends into the divisions *c*, *c*, of the outer main beyond the stops. Hence it escapes by two mouth-pieces, which become united into one pipe. The whole structure is firmly braced with iron hoops. A careful inspection of the engravings will render plain and intelligible what may have been left obscure in the preceding description.

A few special details concerning the pipes may be desirable. The dimensions here given are from my own measurement. It will be perceived in fig. 66, that in each pair of pipes, the space between them near the top is cast solid, so that the surface at this end is in the form of a rectangle with the angles rounded off, 15 in. long by 8 in. broad. On this surface there are two circular holes, 2¼ in. in diameter, of which the centres are on the prolonged axes of the pipes respectively, and which are purposely left in the casting in order to facilitate the withdrawal of the sand-cores of the pipes: they are afterwards plugged up with iron. The length of a pair of pipes was 11 ft. 10½ in.; the diameter externally of each pipe was 8 in., and that of the bore 4 in., so that the thickness was 2 in., whereas I was informed it should only have been 1½ in.; but according to Mr. Marten, the best thickness is 1 in. The surface extending along the junction of the pipes of each pair, from the solid portion at the top to within a short distance from the bottom, was flat, and 2 in. in width. At 8 in. from the bottom each pipe tapered off downwards, and at the bottom the iron was reduced to ½ in. or ⅜ in. in thickness; the lower ends became entirely separate at 4½ in. from the bottom. The lower ends or feet thus tapered off spigot fashion, were fitted into the sockets of the main by iron cement as usual. On the sides of each of the pipes composing a pair three circular snugs were cast on, and there was another similar one in the centre of the solid part at the top. By means of these snugs the pipes when set in the mains are kept firm and apart.

The merit of the invention of this oven is assigned by Mr. Marten to Mr. Martin Baldwin, of Bilston, South Staffordshire, who erected the first oven of the kind in 1851. Experience has now fully established its excellence in the following respects:—The socket-joints of the pipes are not disturbed either by the expansion and contraction of the main, or of the pipes themselves, whereby leakage is prevented; and the pipes are not liable to fracture or to burn down. With respect to freedom from fracture or leakage of joints, Mr. Marten pronounces this oven to be "very greatly superior to any others;" and he states from his own per-

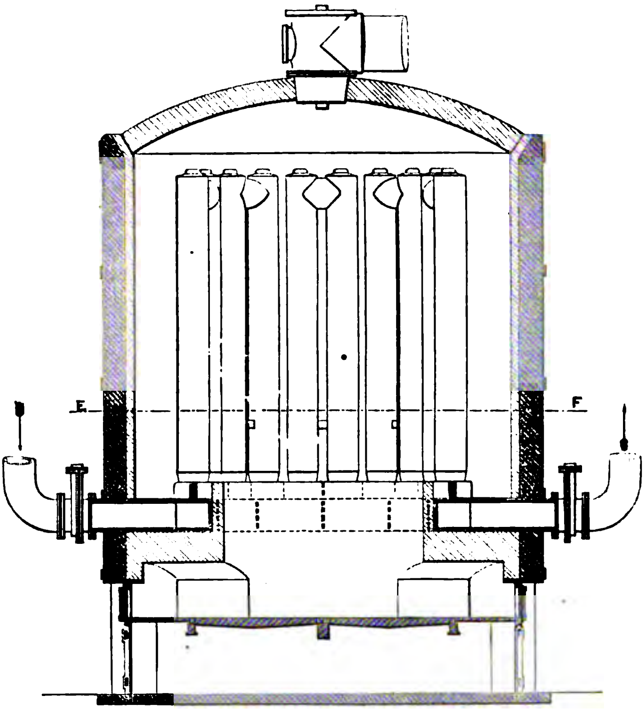
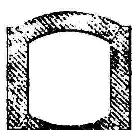


Fig. 73. Vertical Section of round box-foot oven on the line A B, fig. 74.



Section of flue, fig. 75.

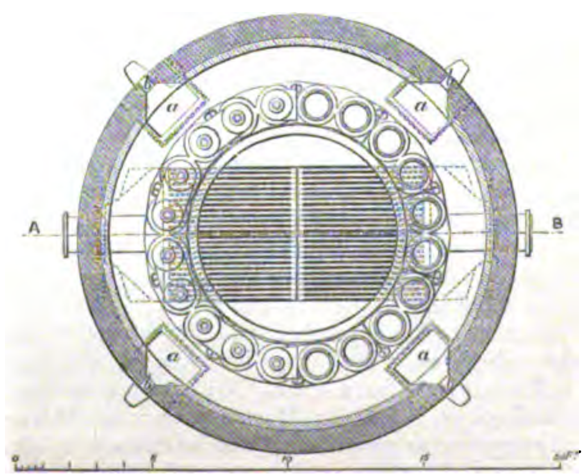


Fig. 74. Horizontal Section of round box foot oven on the line E F, fig. 73.

sonal experience, that out of nearly 400 of these joints which had been under his daily inspection at his own works, and some of which had been made upwards of five years, not one had failed or had to be remade. But in heating power this oven is not superior to some other kinds. In the oven represented in the accompanying engravings there are several improvements over that first erected by Mr. Baldwin, especially the circumferential arrangement of the flues at the top, whereby the heat is more equably and more effectively distributed.

It occurred to Mr. Marten that it might be desirable to fill up a certain amount of the vacant central space of the round oven with a cylindrical core of brickwork; and, accordingly, at his suggestion, such an oven was erected in 1857 at Messrs. Allaway's Iron-works in the Forest of Dean. This modification, Mr. Marten states, was found to be a valuable improvement, "increasing the heating capacity of the round oven to the extent of one-third with a smaller consumption of fuel;" in affording a greater amount of reverberating surface; in

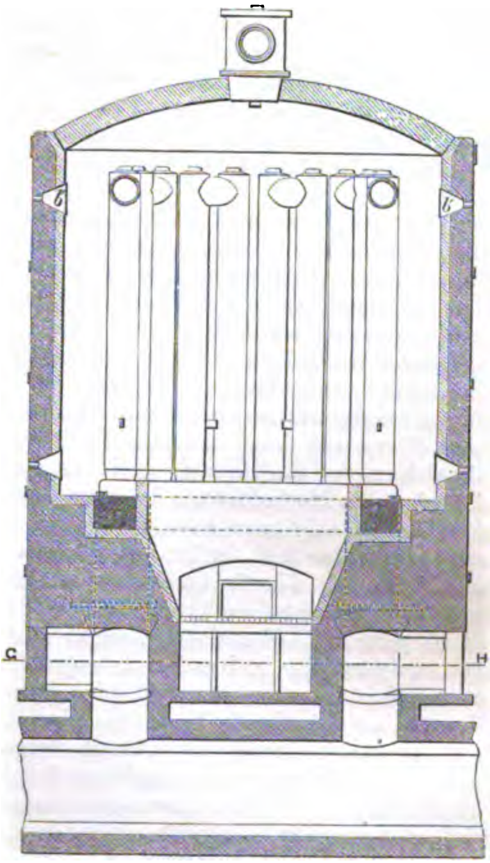


Fig. 75. Vertical Section of round box-foot oven on the line C D, fig. 76.

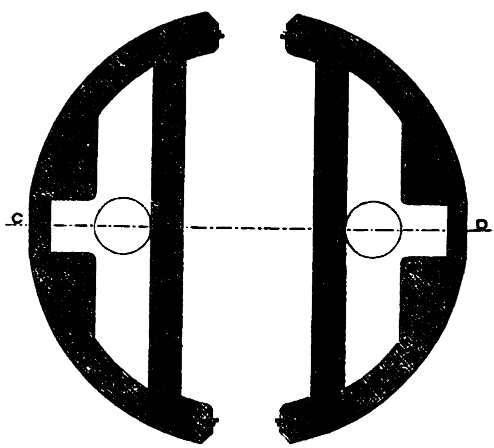


Fig. 76. Horizontal Section of round box-foot oven on the line G H, fig. 75.

rendering the temperature more uniform, the heated core forming, as it were, a reservoir of heat; and in causing a much larger amount of the products of combustion to come into contact with the pipes.[6] The area of fire-grate in this oven was 38 ft. square, and the area of direct heating surface of the pipes 850 ft. square, or 280 ft. square per twyer for 3 twyers; and it was capable of heating the blast for 3 twyers to 800° F.

Mr. Marten informs me (June 2nd, 1863) that, since the publication of his paper, he has constructed an oven with the following deviations from the round oven above described. The semicircular mains are separated completely from each other by the interposition of a central core of brickwork, which divides the oven into two distinct chambers, thus forming in reality two ovens. There are two corresponding fireplaces, with fireholes on the same side.

Round box-foot oven.—An oven of this kind has been erected by Messrs. Perry and Sons, of Highfields Foundry, near Bilston, South Staffordshire, for the Barber's Field Iron Company, Bilston. I am indebted to Mr. Marten for the drawings from which the accompanying engravings of this oven have been executed. Fig. 73 is a vertical section on the line A B, fig. 74. Fig. 74 is a horizontal section on the line E F, fig. 73. Fig. 75 is a vertical section on the line C D, fig. 76. Fig. 76 is a horizontal section on the line G H, fig. 75. It consists, as will be perceived, of a single circular row of cylindrical cast-iron pipes, set vertically in box-feet arranged in a circle. The pipes are cast together in pairs, and each pipe is entirely separate from its fellow, being united only by a cross pipe at the top, and a junction piece towards the lower part, Siamese twins fashion. There are two fire holes opposite each other, and one fireplace which communicates with the heating chamber above by a large central circular opening, and four openings or flues, with sliding dampers, communicating with the space between the exterior of the pipes and the interior of the chamber, fig. 74, *a*, *a*, *a*, *a*. Immediately above each damper is a sight-hole, fig. 74, *b*, *b*, *b*, *b*, whereby the interior of the oven may be inspected; and there are also similar sight-holes near the top, fig. 75, *b′*, *b′*. The box-feet are clamped together with wrought-iron links, embracing snugs on the upper contiguous portions of the box-feet: see fig. 74. This oven is so constructed as to admit of being fired either with coal or the waste gas of the blast-furnaces. The descriptions of ovens, which have been previously given, and the illustrative engravings, render further explanation superfluous.

The cold-blast enters at one box-foot only, one-half passing upwards through the left-hand pipe, and the other half through the right-hand pipe, thus being split into two equal currents. At its exit at the opposite end these two currents unite and escape through one opening. The working of this oven is reported to be very satisfactory. The repair or renewal of mains on the box-foot plan is more readily effected than in the continuous semicircular main. The castings, more-

[6] Op. cit. p. 82.

over, are lighter in each piece, and a defective portion is renewed at very little cost. Mr. Marten informs me that ovens of the kind in question are in successful operation at Messrs. Schneider and Hannay's Works, Ulverstone.

Mr. Marten thinks it advisable that there should be a core in the central hollow space, and that the space between the outside of the range of pipes and the surrounding wall should be contracted. On this point his experience leads him to the conclusion that to obtain the greatest advantage from the reverberatory principle, the inside casing of the round or oval ovens should not be more than 6 inches from the back of the upright pipes; and that the central core should be at the same distance from the inner side of the pipes for a length of about two-thirds the height of the pipes from the top, but opening out away from the foot of the pipes, as otherwise they would soon be destroyed by the intense heat there, owing to the proximity of the fire.

Oval oven.—Mr. Josiah Smith inserted a straight length of main between the contiguous ends of each of the semicircular mains, and so was enabled to increase the number of pairs of pipes from 24 to 33 in each oven. This, according to Mr. Marten, was found to be so great an improvement on the ordinary round oven, that another oval oven was erected, in which the mains were further elongated so as to receive 36 pairs of pipes; the area of fire-grate was also proportionately increased, and a middle partition wall built between the two mains, whereby the oven was divided into two distinct compartments, so that one of these could be cleaned out at any time without interfering with the other.[7]

Subsequently, at the Parkfield Furnaces, near Wolverhampton, an oven on the same principle was constructed, with the addition of a central core of brickwork increasing regularly upwards in diameter. The area of fire-grate was 56 ft. square, and that of direct heating surface of the pipes 1350 ft. square. It heated the blast for 7 twyers to 800° F. Another oven of this kind was erected in 1858 at the same works with 40 pairs of pipes, in which the area of fire-grate was 54 ft. square, and that of direct heating surface of the pipes 1500 ft. square, or 250 ft. square per twyer for 6 twyers. Such an oven would be capable of heating the blast for 10 twyers, "if pushed a little in the firing." These ovens required good workmanship in their construction.

In order to cleanse the oven without stopping the blast, small cast-iron box frames with doors were inserted in the brickwork opposite the top flues respectively. With the same object small box frames were also inserted opposite the spaces respectively between the pipes near the socket-joints.

Formerly 8 or 10 cwts. of slack (Staffordshire non-caking coal rich in oxygen) were required per ton of pig-iron to heat the blast to 320° F.; whereas, in the oval oven, 5 cwts., or even 4½ cwts., now suffice per ton of pig-iron to heat the blast uniformly to 800° F.

[7] Op. cit. p. 83.

With respect to the large oval oven, Mr. Marten wrote to me as follows, June 2nd, 1863:—"We are working furnaces now, the blast of which is heated only with one large oval oven; but the result of my experience is, that two of the small oval ovens to each furnace are better. The danger of the large oval oven is lest the core, which overhangs some feet, should loosen and drop; and besides, where there are so many pipes in one chamber, there is greater danger of their being burnt than when they are distributed through more chambers. The two small oval ovens with four chambers can be built at as little cost as one large oval one. There is also this advantage in working with two small ovens divided into small separate chambers: in the event of anything being wrong with the oven, one chamber can be taken off, which with two small ovens only reduces the heating surface 25 %, or one chamber out of four; whereas if dependence is placed on one large oven and anything is wrong, the heating surface is reduced 50 %, where there are only two chambers."

In all hot-blast ovens, especially when several are connected together by blast mains, it is essential that there should be efficient stop-valves, one at the cold end and another at the hot end of each oven, so that any particular oven may be conveniently isolated from the general arrangement. Formerly old-fashioned disc throttle-valves were employed, which acted very imperfectly, and which used occasionally to stick or be blown out of shape, and so became leaky. Slide valves are now employed, and with complete success. "These valves also," Mr. Marten remarks, "give a ready and simple mode of testing the state of repair of each oven from time to time; for by shutting off each oven alternately and watching its effect on the speed of the engine, the leakage per oven can be observed with great exactness. In large works, without such a means of detection, leakages to the extent of 500 or 1000 cubic feet of blast per minute would frequently take place for months without any certain means of tracing them."[5] It is, moreover, essential to shut off communication between the hot-blast mains and the furnace, when the blowing engine is stopped, in order to prevent the possibility of the efflux of the gases of the furnace into the hot-blast apparatus, and which would subsequently explode, jarring both the pipes and their joints.

Theory of the Hot-Blast.

After the positive, oft-repeated, and generally credited statements, which have been put forth concerning the extraordinary effect of the hot-blast in diminishing the consumption of fuel in the smelting of iron, it might seem superfluous to raise any question as to the fact. It has been asserted that there are more false facts,—a somewhat paradoxical expression,—than false theories in the world. There are, no doubt, a vast number of both; but whether this numerical relation between them be correct, I will not venture to decide. However this

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[5] Op. cit. p. 74.

may be, the great economical results attributed to the hot-blast have recently been called in question by the author of a work, which in its own preface is pronounced to be "the most complete and practical treatise on the metallurgy of iron to be found in the English language:"—I refer to that of the late Mr. Truran, son of the engineer of the Dowlais Iron-works, who, as previously announced, was asphyxiated by the blast-furnace gases.[9] This treatise is often quoted, especially by foreign writers, and has, moreover, obtained a wide circulation in this country, as may be inferred from its having reached a second edition. On this account, and because, I believe, it contains much fallacious reasoning with not a few pernicious errors, particularly with reference to the hot-blast and the utilization of the waste gas of the blast-furnace, I shall examine some of Mr. Truran's doctrines with more detail than they intrinsically deserve.

Mr. Truran considered that effects have been solely ascribed to the hot-blast, which in a considerable degree are due to other causes; and that consequently there has been confusion between the *post hoc* and the *propter hoc*, an error even now-a-days by no means of rare occurrence. He expressed his conviction in the following terms:—"The saving in fuel and increase of make due to it [hot-blast] is not in general one-fourth of that which has been asserted to have been effected. Some have even gone so far as to state that by the mere substitution of heated air for the cold air formerly used, two-thirds of the coal requisite for smelting a ton of pig-iron were saved at the Scotch iron-works,—among others, the late Mr. Mushet. Before the introduction of the hot-blast the consumption of coal at the Clyde Works in smelting is stated by that gentleman to average 7 tons 3 cwts. This appears to have been the quantity used in the year 1797."[1] An extract from Mr. Mushet's book is then given to prove that such was the fact. For 1 ton of pig-iron the materials consumed were,

	Tons.	Cwts.	Qrs.	Lbs.
Coal for coking	7	8	0	4
Ironstone (raw)	3	1	2	0
Iron ore	0	2	0	0
Limestone	0	17	1	4
Engine coal, including coal for calcining	3	16	0	0

Then follows a statement, which Mr. Mushet published to show the diminished consumption of fuel at the same works in 1839, when the hot-blast was in operation. At that time the materials required to make 1 ton of pig-iron were,

	Tons.	Cwts.	Qrs.
Coal	2	3	2
Calcined mine [ironstone]	2	6	2
Limestone	0	11	2

"The lapse of a period of 42 years," wrote Mr. Truran, "showing

[9] "The Iron Manufacture of Great Britain, Theoretically and Practically Considered." By W. Truran, C.E. 2nd ed. Revised from the M.S. of the late Mr. Truran, by J. Arthur Phillips and William H. Dorman, C.E. London, 1862. 4to. pp. 251. The work is well illustrated with 84 lithograph plates, from drawings by Mr. Truran, who was an able mechanical draughtsman, and died prematurely, I believe, from pulmonary consumption.

[1] Op. cit. p. 142.

us a reduction of 5 tons on the quantity of fuel required for 1 ton of pig-iron. This saving is carried 'at once' to the credit of the hot-blast. With all deference to the acknowledged authority on matters connected with iron-making of the late Mr. Mushet, we must confess that in our opinion the saving of fuel due to the use of heated air would be more nearly represented by 5 cwts. than 5 tons. For if we are to attribute the whole of this saving to the hot blast, we must also maintain that in the 42 years between 1797 and 1839, with the exception of this single improvement, the iron-manufacture remained stationary. But we know that this was not the case, for during that period very great improvements were made in the preparation of the fuel and ironstone, as also in the furnaces and blowing engines."

Now, it is well known that the metallurgic arts have remained stationary during long periods, and this is specially true of the smelting and manufacture of iron, as will be fully established in the course of this work. The assumption, therefore, which Mr. Truran regarded as involved in the preceding statements of Mr. Mushet goes for nothing. But, supposing otherwise, no assumption of this kind can countervail a well-grounded positive statement. What is the fact? I have already answered the question by stating on evidence, the accuracy of which there is not the slightest reason to doubt, that during the first six months of the year 1829, when cold-blast was exclusively used at the Clyde Iron-works, the coke from 8 tons 1¼ cwt. of coal was required to produce 1 ton of pig-iron; and that during the first six months of the following year, by the use of blast heated only to 300° F., all other conditions being similar, the amount required to produce 1 ton of pig-iron was reduced to 5 tons 3¼ cwts. It would be superfluous to repeat the additional evidence afterwards obtained at the same works in favour of the saving of fuel effected by the hot-blast. It is surprising that Mr. Truran should have so completely neglected or ignored such positive information as this; and equally so that the posthumous edition of his treatise should have been reprinted without even a comment on the subject.

Mr. Truran appealed to the experience of the Dowlais Iron-works in corroboration of his views. In 1791 the consumption of materials at these works to produce 1 ton of pig-iron is stated to have been,

	Tons.	Cwts.	Qrs.
Coal for coking	6	6	0
Ironstone (calcined)	2	18	0
Limestone	1	8	0
Engine coal	1	15	0

In 1831 the consumption of materials at the Dowlais Works in making 1 ton of foundry pig-iron with cold-blast is stated to have been,

	Tons.	Cwts.	Qrs.
Coal	2	10	0
Ironstone (calcined)	2	16	0
Limestone	0	18	0
Engine coal	0	10	2
Coal for calcining	0	6	2

Hence, Mr. Truran concluded that the improvements in smelting at the Dowlais Works during 40 years were such, that while still using cold-blast, there had been a reduction of $\frac{2}{5}$ of the quantity of coal needed to produce 1 ton of pig-iron; and that, consequently, "other causes besides the use of a heated blast have shared in producing this remarkable saving of fuel."

Without disputing the correctness of the foregoing data, or the conclusion that owing to improvements in the furnaces, etc., at Dowlais and in the mode of working them considerable saving of fuel might have been effected, still it by no means follows that similar progress should have been made in Scotland. Indeed, as we have seen, there is direct positive evidence to the contrary. But one very important point should be borne in mind, namely, that at the Clyde Iron-works the experiments which first established the value of the hot-blast were made under conditions exactly comparable; whereas, the conditions in 1791 and 1831 at the Dowlais Iron-works must have been widely dissimilar on Mr. Truran's own showing.

Mr. Truran seems entirely to have disregarded the great difference in the quality of the coal used at the Dowlais and Clyde Iron-works respectively; a difference which has been fully explained in the First Part of this work, and the importance of which will be immediately appreciated when the composition of these two kinds of coal is remembered.

It might surely have been imagined that the Scotch ironmasters would not have been such incompetent observers and shallow reasoners, as to have been so grossly misled in their estimate of the value of the hot-blast in saving fuel, as Mr. Truran seems to have believed. The Messrs. Baird would hardly have incurred the heavy expenditure of the great Neilson trial, unless they had been thoroughly convinced by ample experience that the action was worth defending. With regard to presumptive proof, at least, in favour of the advantage of the hot-blast, it is impossible to conceive any thing stronger than the course which they pursued.

In Swedish blast-furnaces, working with charcoal and lake and bog iron-ores on hot-blast, at about 350° C., and producing very grey iron, or, as it is termed, foundry iron, the average saving of fuel is estimated at 33 %, compared with similar furnaces supplied with the same materials, and working on cold-blast, but yielding pig-iron less grey and of better quality.[2] In furnaces working with mountain ores on hot-blast at 200° C., and yielding mottled pig-iron, the estimated saving of charcoal is 20 %. By way of illustration I introduce the following actual details of working which have been published by Mr. Sandberg, under the authority of the Board of Swedish Ironmasters. In 1858 hot-blast, at about 350° C., was first applied at the Storebro furnace in Småland, under the management of Mr. Sandberg, and working with lake and bog ores on foundry iron, when, for a given weight of pig-iron, the volume of charcoal was reduced on the average from 17·8 to 11·6,

[2] Jern-Kontorets Annaler, 1859, p. 273.

which is about 35 %. At about the same period, in the Ankarsrum furnace, also in Småland, hot-blast at 200° C., which had previously been in operation during several months, was replaced by cold-blast, on account of repairs being required in the heating apparatus, or some other contingency. Mottled pig-iron was made at this furnace from mountain ores. After this change, in order to produce the same description of pig-iron, a reduction of 20 % in the weight of the ore, relatively to the charge of fuel, became necessary, or, in other words, the same volume of charcoal smelted ⅕ less ore.

With regard to make, Mr. Truran admits that there was an increase due to hot-blast, "but not more than 10 %."[3] And in support of this he compares the yields of various hot and cold blast furnaces, without, however, presenting such details as are absolutely necessary to enable his readers to form their own judgment on the subject. The make, in cold as well as in hot blast furnaces, differs greatly, not only in furnaces of different shape, but also in the same furnace under different conditions of smelting, such as relate to the nature of the ore, the quality of the fuel, and the amount of blast injected into the furnace in a given time.

In Mr. Truran's book is a chapter on the "Economy of heated air, etc.," containing somewhat remarkable statements and singular deductions therefrom, which, after attentive and repeated perusal, I am unable clearly to comprehend. This may be due to myself, and not to any fault of the author. I will, however, give one or two extracts to enable the reader to decide for himself where the blame lies.

In reference to certain Scotch furnaces, in which black-band ironstone was smelted with raw coal and hot-blast, the following statement is made :—"In the instance quoted, where the largest proportion of air to carbon obtains, the quantity of oxygen is barely sufficient to form carbonic oxide, but the production of this gas in the zone of fusion involves the supposition of a temperature greatly below the melting-point of the ore. Besides which, the quantity of oxygen received by the Scotch furnaces is not more than the half of that necessary for the production of this gas, and is altogether insufficient to enter into combination with the carbon in any known proportions."[4]

I am not aware that the production of carbonic oxide in the zone of fusion involves any such supposition as that announced. If the statement in the last sentence of the preceding extract be correct, it would be interesting to know what becomes of the large amount of carbon which escapes oxidation by the blast, and which, it seems to be intimated, exceeds the amount of carbon volatilized from the coal during its conversion into coke, with the addition of that consumed in the carburization of the iron.

Mr. Truran laid much stress on the evil resulting from combustion of a portion of the fuel in the throat, especially of coal-fed furnaces with narrow throats; and stated, moreover, that the destruction from this cause was less in hot-blast than in cold-blast furnaces. "To under-

[3] Op. cit. p. 144.

[4] Op. cit. p. 162.

stand this apparent paradox," he wrote, "it must be remembered that the heat maintained in the throat of the furnace is not produced from conduction below, but is the result of a partial combustion of the fuel which is governed by the velocity of the ascending current, and that again by the area of escape and the volume of the gas. . . . The economy of fuel with the heated blast is doubtless to a great extent due to the comparative coolness maintained in the throat, the consumption of fuel being less in that region than in a cold-blast furnace. If then we could lower the temperature in the throat, greater economy of fuel would be ensured, and the superiority of the heated blast in this respect disappear." [5] In support of this opinion it is asserted that "when a furnace which has been working with a heated blast, and the accompanying reduced quantity of coal, is suddenly changed to a cold-blast by withdrawing the fires from the stoves, the descent of the materials is accelerated. For 24 to 30 hours after the substitution of the cold-blast, the furnace makes more iron with the original burden, and *no deterioration is to be seen in the quality of the produce.* [The italics are mine.] But after that period the rate of descent is checked, and the quality changes; in from 36 to 40 hours the furnace will have returned to its original rate of working, and the quality of the iron be deteriorated to white. At the end of 48 to 60 hours the furnace will have settled down to the usual rate of working with a cold-blast, and the quality have finally receded to that produced under ordinary circumstances with the diminished consumption of coal. If the coal is increased sufficiently to keep the furnace with cold-blast permanently on the quality of iron it was making before the alteration, the make will be diminished in the ratio that the altered quantity of ore bears to the whole of the materials charged. When the make with a hot-blast has averaged 105 tons a week, the immediate substitution of a cold-blast has temporarily increased the production at a rate equal to a weekly make of 115 or 116 tons; but when the increased quantity of coal, added as a compensation for the withdrawal of the hot-blast, has taken effect, the make has receded to 96 tons weekly." [6]

With regard to the alleged consumption of fuel in the throat of the blast-furnace, it is absolutely certain that no combustion can take place there, except by the aid of atmospheric air from without; for all the analyses, previously inserted, of the gases escaping from the mouths of blast-furnaces, agree in one particular—the entire absence of uncombined oxygen. And from observations, also previously inserted, on the temperature of different regions of the blast-furnace, it may be safely concluded that in the throats of blast-furnaces carbonic acid cannot be converted into carbonic oxide by contact with carbon. Further, it is difficult to conceive how the solid fuel at the top of the blast-furnace should undergo combustion, as it is enveloped in an ascending current of gas which contains no supporter of combustion. The assertion of Mr. Truran, therefore, concerning the consumption, properly so called, *i. e.* by oxidation, of coal or other fuel in the throat of the blast-furnace,

[5] Op. cit. p. 164. [6] Op. cit. p. 165.

is, to say the least, unsupported by strong arguments. Any combustion which may take place there must result from the action of the surrounding atmospheric air upon the volatile products evolved from the mouth; and if this be admitted, much of Mr. Truran's reasoning necessarily falls to the ground.

The statement concerning the accelerated descent of materials, and the increase of make corresponding to a sudden change from hot-blast to cold-blast, is certainly striking. This temporary increase of make, we are informed, is known to many furnace-managers, but has never been in the slightest degree alluded to by any writers on the metallurgy of iron.[7] Mr. Truran puts the question, "If the heating of the air were the real cause of the larger make and greater economy of fuel, how is it that the make is augmented and the economy greatest on substituting a cold-blast under the circumstances we have described (*i.e.* those preceding)?" Mr. Truran gave an answer founded on certain considerations with respect to the consumption of fuel in, and the temperature of, the throat. It is certainly not satisfactory to me.

Being desirous of obtaining additional information concerning the alleged increase of make immediately following the change from hot to cold blast, I sought it from Mr. Parry, who has had such extensive opportunities of observing the working of blast-furnaces at the Ebbw Vale Iron-works, and has applied his powers of accurate observation to all that concerns the smelting and manufacture of iron with great success. Mr. Parry promptly communicated to me the following remarks upon the subject:[8]—"When the fires are withdrawn from the heating-stoves of a blast-furnace, for the purpose of using a cold-blast, the diameter of the blowpipes is not immediately reduced. Hence more air must necessarily pass into the furnace in a given time, as its temperature gradually falls and bulk decreases, and the furnace must consequently *drive faster* and produce more iron, till the fresh charges introduced at the throat reach near the bottom. The whole mass of minerals from top to hearth was, when the fires were withdrawn, at the higher temperature of the hot-blast furnace, and would bear for a time an extra driving; but not so when the furnace became filled with a hot-blast burden to be blown with cold air. In that case the layer of fuel at the twyers would be so diminished in depth that the reduced ores would come under the influence of the oxygen of the blast, and burn into a black scouring cinder. I have often seen stoves let out for repairs for a short time without producing any material effect on the working of the blast-furnace. There is a storehouse of extra heat above which is not soon exhausted; but when that is gone the effects are ruinous, unless the burden of ore and the diameter of the blowpipes be reduced. A case occurred some years ago here of that kind in a lawsuit with Neilson. I see no other explanation of Truran's statement, which is no doubt correct, and just what any one would expect who understands the true theory of hot-blast, which he does not appear to have done."

Mr. Truran wound up his observations on the "Economy of Heated

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[7] Op. cit. foot-note, p. 166. [8] August 2, 1863.

Air, etc.," with "Additional Remarks on the Hot-Blast;" and in these he ventured to criticise the researches of Bunsen, Scheerer, Ebelmen, and others, on the composition of the blast-furnace gases. He gave his opinion in a somewhat judicial style in the following terms:—"Altogether, we are of opinion that the labour expended by chemists in this instance has been misdirected, and the collection and combustion of the gases is but a clumsy expedient for obtaining some service from the carbon charged in excess of the absolute requirements of the furnace. As a proof that chemists, in their researches into the nature of the waste gases, have not directed their attention to the causes which conduce to the presence of carbonic oxide, neither Messrs. Bunsen nor Playfair, nor the Continental chemists, have given the quantity of atmospheric air delivered into the furnaces under experiment."[9]

The nonsense contained in these extracts is unworthy of criticism, and will be obvious to every one who has an elementary knowledge of the chemistry of combustion, and has studied what has been written on the utilization of the waste gas. It is evident that Mr. Truran was very imperfectly informed on this part of his subject. Some persons may be inclined to accuse me of employing language too severe, especially in reference to the opinions of a dead man. It may be so; but I prefer to use plain words which express my convictions to circumlocution which would not. Even the editors of Mr. Truran's treatise confess that "with some of his observations of a theoretical nature" they cannot "entirely agree." But this extremely mild and qualified expression of dissent will not go far towards counteracting the mischievous effect of Mr. Truran's fallacious reasoning on several practical questions of great importance.

We have now to consider the cause of the remarkable saving of fuel effected by the hot-blast. From the decisive comparative results with cold and hot blast at the Clyde furnaces, under similar conditions, and from the innumerable results which have since been obtained by competent and trustworthy observers in various localities, it may be certainly concluded that, *cæteris paribus*, much less fuel is required to produce a given weight of pig-iron, even when the blast is only moderately heated, than when it is not heated at all. Now, as under both conditions the fuel is wholly consumed, and as the gas also which escapes from the furnace-mouth has substantially the same composition, it follows that the *amount* of heat generated in a furnace working with cold-blast is enormously greater for a given weight of pig-iron than in one working with hot-blast, the conditions with respect to quality of ore and fuel, dimensions of the furnace, etc., being supposed to be the same in both cases. In this consideration it is of course to be understood that account is taken of the fuel consumed in heating the blast and raising steam for the blowing engine. It is therefore plain that mere quantity of heat, *i. e.* the number of units of heat evolved, can have little to do with the matter. This being admitted, the inevitable conclusion is that *calorific intensity* must be concerned, and that the tem-

[9] Op. cit. p. 172.

perature of what may be designated the most active part of the furnace must be higher in the case of hot-blast than in the case of cold-blast. This, indeed, is proved to be the case, at least in the vicinity of the twyers; for in a hot-blast furnace water-twyers are absolutely essential, as other twyers, which may be employed in a cold-blast furnace, would be soon burned away. Besides, the "eye" or spot of light seen through the twyer of a hot-blast furnace is intensely bright, compared with that in a cold-blast furnace; and, moreover, the slag prolongation of the twyer in the former, or "nose," is exceptional, while there is generally one in the latter, in the one case the temperature being sufficient to fuse the slag, and in the other not. Let us suppose, for the sake of argument, that a metal requires exactly 1000° C. for its fusion; it might be subjected to a temperature of 999° C. for ever without melting. Just so may it be in the blast-furnace with respect to the carburization of the reduced iron and certain other accompanying chemical actions, which, moreover, may take place with slowness at one temperature and with rapidity at another slightly more elevated. In order to produce these actions in a furnace on cold-blast, it is requisite to consume a much larger quantity of coal than in a furnace on hot-blast. A few degrees of temperature more or less may make all the difference.

But this can hardly be regarded as a scientific explanation of the greater efficacy of hot-blast as compared with cold-blast; it is rather a statement of fact than a theory. It remains therefore to search for a more proximate cause.

The air of cold-blast must expand immensely on passing from the twyer into the furnace, and thereby cause the abstraction of a large amount of otherwise available heat.[1] It should be borne in mind that in a furnace on cold-blast there is generally a nose or tube-like prolongation of solidified slag from the end of the twyer, sometimes extending even across the upper part of the hearth; and, when there are two or more twyers, the noses may meet, and as it were, anastomose in an irregular manner.[2] The air in traversing these noses, which may be regarded as a sort of hot-blast apparatus in the furnace itself, is prevented from acting on the incandescent fuel in a given limited zone, where the heat should be as concentrated as possible, so as to produce the maximum temperature required; but, on the contrary, it is

[1] The following table, showing the dilatation by heat of air and some other gases, may be useful. Regnault, Cours de Physique, Janin, 2, p. 67.

Dilatation between 0° *and* 100° C.

	Under constant volume.	Under constant pressure.
Hydrogen	0·3667	0·3661
Air	0·3665	0·3670
Nitrogen	0·3668	
Carbonic oxide	0·3667	0·3669
Carbonic acid	0·3688	0·3710
Sulphurous acid	0·3845	0·3903
Cyanogen	0·3829	0·3877

[2] Mushet states, that at the Clydach Iron-works, in South Wales, a vitreous tube extended from the end of one of the twyers across the hearth to the opposite wall, and from thence ascended obliquely towards the back wall, where the blast then escaped. No light was seen at the twyers for many days, and at last the solid mass of masonry was penetrated by the action of the blast, so as to bring a body of flame to the outer surface, which in a very short time would have destroyed the building. After making every effort to remedy the evil, the furnace was stopped, and the whole of the interior taken out. Papers on Iron and Steel, p. 348.

distributed over a larger space, with a proportionate diminution of temperature in the vicinity of the twyers.

The air of hot-blast enters the furnace already highly expanded, and in so far the loss of the heat required for this degree of expansion is avoided. Moreover, immediately on leaving the twyer, the blast, owing to the absence of noses, comes in direct contact with the incandescent fuel, and produces great elevation of temperature.

In the cold-blast furnace the space between the blast-pipe and the twyer is not stopped up, and there is, consequently, much regurgitation of the air injected; whereas, in the hot-blast furnace the space above mentioned is closed, and the whole of the air injected becomes effective. But escape of air implies loss of fuel, in as much as a corresponding amount of steam-power has been expended in vain. At the Cyfartha furnaces of Messrs. Crawshay, working on cold-blast, I was much struck with the amount of air which escaped backwards from the twyer.

For a given *volume*, cold-blast of course contains a much greater *weight* of oxygen than hot-blast, and it might therefore have been expected that the additional heat capable of being evolved by cold-blast would have far more than compensated for the sensible heat of hot-blast. With respect to *quantity* of heat it would be easy to deduce from the principles laid down in the First Part of this work, that this must certainly be the case. On the other hand, for a given *weight* of blast the reverse would occur.

But, supposing that oxygen when heated combines with incandescent carbon more rapidly than when cold; or, in other words, that combustion is more quickly effected by hot-blast than cold-blast; then, it is evident that there must be a proportionate increase of temperature, for, *cæteris paribus*, temperature will be in the direct ratio of rapidity of combustion.[3] Now, observation seems clearly to have established the correctness of the supposition in question.

My friend Mr. Sandberg has communicated to me the following striking fact, which may be adduced in illustration. In the Swedish gas-welding or re-heating furnace (described in the sequel p. 717), if the current of gas from the generator be burned by cold-blast injected through the openings *l l*, etc., a blue flame will extend quite to the stack end of the furnace, and the temperature will not suffice to raise the iron to a welding heat. Whereas, if hot-blast be substituted for cold-blast, the flame will not extend sensibly beyond the bridge *n*, to the left of, and facing the fire-bridge *m*, and the temperature in the space between these two bridges will be so high as to melt even wrought-iron with comparative facility. It would be difficult to conceive stronger evidence than this in confirmation of the statement that combustion is quicker with hot than with cold-blast.

We may, then, conclude with respect both to solid and gaseous fuel, that hot-blast will occasion more active combustion, and, consequently, a higher temperature than cold-blast, at least up to the limits of temperature to which the blast is usually heated.

[3] Vid. Metallurgy, First Part, p. 51.

Accepting the foregoing conclusion as established, we should be disposed to infer that the efficacy of hot-blast would be most manifest in the case of fuel *comparatively* difficult of combustion, such as coke; and, accordingly, if I mistake not, this is the fact, the saving of fuel in the case of charcoal being least, and charcoal of all fuels employed in the blast-furnace being the most readily combustible.

To the question, why should hot-blast cause quicker combustion than cold-blast, I can give no satisfactory answer, any more than I can to the question, why should certain bodies dissolve in much larger proportion in hot than in cold water. At present we must be content with the simple enunciation of both these facts, although we may reasonably expect that hereafter something like a solution of them may be arrived at.

Mr. Siemens, the inventor of the so-called regenerative furnaces, than which, in my judgment, nothing can be more philosophical in principle, proposed to employ blast at a much higher temperature than hitherto, considerably exceeding even a red heat; and the proposal has been carried into practice by my friend Mr. I. Lowthian Bell, at the Clarence Iron-works, near Middlesboro'-on-Tees. No advantage, however, was derived from thus heating the blast. Great inconvenience is reported to have been experienced from the accumulation of dust in the regenerative chambers, and the Siemens' hot-blast stoves have been abandoned at these works.[4]

Water Twyers.

The water twyer, as previously stated, is essential where hot-blast is applied. At the Neilson trial the time of the invention of this twyer was the subject of much controversy. It was deposed that it had been practically used long anterior to the hot-blast; but the invention of it is claimed for Mr. Condie. Mr. John Campbell, jun., has supplied me with the following statement of his father on the subject, who was an actor in the whole proceedings connected with the early history of the hot-blast.[5] "Condie was engaged at Calder by Mr. Dixon to make experiments, but Mr. Alexander Christie, the manager, being at that time hostile to the hot-blast, the experiments did not get fair play, and Mr. Dixon in consequence sent Condie to Nelsontown as manager, with instructions to experiment, and it was there he invented the water twyer. Mr. Dixon afterwards discovered that, instead of coke, raw coal could be used, at of course a greatly reduced cost, and proposed taking a patent for it; but the patentees of the hot-blast proposed instead to give him two furnaces at Calder free of licence

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[4] Since the above was in type, I have been informed by Mr. Cowper that hot-blast stoves on his method of construction have been in successful operation for upwards of two years at the works of Messrs. Cochrane and Co., at Ormesby, near Middlesboro'-on-Tees; and that the result has been a saving of 5 cwts. of coke per ton of iron made, and an increased make from the same furnace of more than one-third. The blast is heated considerably above redness.

[5] Dated from the Calder and Govan Iron Wharf, Blackfriars, London, Dec. 12, 1861.

duty, and one-third of anything they received above 1*s*. per ton. An agreement was drawn up to this effect; but as the patentees afterwards fixed the licence duty at 1*s*. per ton, the agreement was never signed. Mr. Dixon was, however, allowed the privilege of the two furnaces to the end, for his great expense in testing and bringing the patent to a useful purpose. Condie never received a sixpence for the water twyer, without which the patent [for the hot-blast] was worthless." Mr. Campbell, jun., informs me that "these details never appeared in print, as the late Mr. Dixon studiously avoided any publicity."

The case being as thus represented on authority, it will, I think, be admitted that Mr. Condie was, to say the least, ungenerously treated. But how often have similar cases occurred! Capitalists have frequently availed themselves of the brains of poor inventors, without bestowing an adequate reward, if, perchance, they have bestowed any. I have heard one of these gentlemen, himself engaged, as moneyed partner, in large metallurgical operations, coolly declare that brains are more abundant in the world than capital, and ought, therefore, to be had cheap. This is rather too bad. Wealthy men have been known to reward the honest finder and restorer of valuable treasure which they had lost with a shilling, or, perhaps, half-a-crown for his trouble. The reader will be at no loss to suggest a parallel to such liberality.

The twyer which Condie employed consisted of a coil of wrought-iron tube imbedded in the walls of a short hollow conical pipe of cast-iron. It is made by pouring the molten metal round the coil in a suitable mould, just like the water-tymp before described. Both ends of the coil protrude from the broad base of the cone, one at each side. Water enters at one of these protruding pipes, passes direct to the narrow end of the twyer through a straight length, then circulates back through the coil, and escapes from the opposite protruding pipe. This is now commonly known as the Scotch twyer.

It has been proposed of late to discard the use of cast-iron, and to employ the wrought coil alone as a twyer; and a patent has been secured for this invention. Twyers of this kind are manufactured by Messrs. Knowles and Buxton, Chesterfield. They have been tried at the Ebbw Vale Iron-works, and not approved of. Mr. Levick has tried at the Blaina Iron-works another modification, in which only about half the coil towards the narrow end is surrounded by cast-iron.

The wrought-iron, or Staffordshire twyer, has been already described. In South Wales these twyers are extensively used. As will hereafter be shown, the Staffordshire twyer is employed at the tin-plate works in South Wales, but the axes of the cone do not coincide. Several patents have been taken out for improvements in twyers, but, as far as I have been able to ascertain, none have been proved to have any advantage over the old twyers, and some appear rather absurd than otherwise.

In old books the twyer is called tue-iron, tuiron, and tuarn.[6]

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[6] Vid. The Natural History of Staffordshire. By Robert Plot, LL.D. Oxford, 1686, p. 128.

THE GASES OF IRON-SMELTING BLAST-FURNACES.

It is evident that a knowledge of the composition of the ascending gaseous current in the blast-furnace at every stage from the twyers to the mouth will tend to explain the chemical actions which successively take place; and accordingly, several experimental investigations of this nature have been undertaken, namely, by Bunsen in Germany, by Ebelmen in France, by Scheerer and Langberg in Norway, by Bunsen and Playfair in England, and by Tunner and Richter in Austria. The results have led to the division of the furnace into zones of *specific action*, and these in some metallurgical treatises are defined with a degree of precision more imaginary than real. Illustrative engravings of the interior of furnaces in operation are presented, in which horizontal layers of fuel and ore are shown in alternation from top to bottom, which, on the score of regularity of stratification, would surprise even a geologist, and which are only calculated to mislead.

In treating this subject, the data obtained by the observers above mentioned will first be presented in a condensed form, but not in chronological order, and then will follow deductions therefrom.

Tabular Statement of the Composition of the Gases of Iron-Smelting Blast-Furnaces.

In the horizontal column at the foot of each of the following tables the numbers indicate the proportion by volume of oxygen above or below 26·26, which is the proportion of oxygen by volume associated with 100 parts by volume in atmospheric air. When there is a diminution of the oxygen the sign − will be prefixed.

TABLE I.[7]—Composition by volume of the gases of the furnace at Veckerhagen, Hessen Cassel. *Bunsen.*

Component gases per cent. by volume.	Height above the twyer.						
	17¾ ft.	16¼ ft.	14¾ ft.	13¼ ft.	11¾ ft.	8¾ ft.	5¾ ft.
	Depth below the mouth.						
	3 ft.	4 ft. 5 in.	6 ft.	7ft. 6 in.	9 ft.	12 ft.	15 ft.
	I.	II.	III.	IV.	V.	VI.	VII.
Nitrogen	62·34	62·25	66·29	62·47	63·89	61·45	64·58
Carbonic acid ...	8·77	11·14	3·32	3·44	3·60	7·57	5·97
Carbonic oxide...	24·20	22·24	25·77	30·08	29·27	26·99	26·51
Marsh-gas (CH^2)	3·36	3 10	4·04	2·24	1·07	3·84	1·88
Hydrogen.........	1·33	1·27	0·58	1·77	2·17	0·15	1·06
	7·22	11·10	−2·02	3·32	2·27	8·01	3·50

[7] Brit. Assoc. Rep. 1845, p. 143. Bunsen states that in his original memoir in Poggendorff's Annalen, the composition was, almost without exception, erroneously calculated; and these are the corrected numbers.

TABLE II.[8]—COMPOSITION BY VOLUME OF THE GASES OF THE FURNACE AT BAERUM, NORWAY. *Scheerer and Langberg.*

Component gases per cent. by volume.	Height above the twyer.					
	23 ft.	20½ ft.	18 ft.	15½ ft.	13 ft.	10 ft.
	I.	II.	III.	IV.	V.	VI.
Nitrogen	64·43	62·65	63·20	64·28	66·12	64·97
Carbonic acid ...	22·20	18·21	12·45	4·27	8·50	5·69
Carbonic oxide...	8·04	15·33	18·57	29·17	20·28	26·38
Marsh-gas.........	3·87	1·28	1·27	1·23	1·18	0·00
Hydrogen	1·46	2·53	4·51	1·05	3·92	2·96
	14·43	15·03	8·12	3·06	1·93	2·80

[8] Ann. des Mines, 4. s. 6. p. 3. 1844. Danish feet? If so, the same as the Prussian.

TABLE III., A.[9]—COMPOSITION BY VOLUME OF THE GASES OF THE FURNACE AT CLERVAL, FRANCE. *Ebelmen,* A.D. 1841.

Component gases per cent. by volume.	Height above the twyers in English feet.						
	25⅓	22½	17½	13⅛	9½	8	
	Depth in metres below the mouth, as stated by Ebelmen.						
	At the mouth.	1m 33	2m 67	4m 00	5m 33	5m 67	0m 44 above the twyer.
	I.	II.	III.	IV.	V.	VI.	VII.
Nitrogen	57·79	57·80	58·15	59·14	60·54	63·07	56·08
Carbonic acid ...	12·88	13·96	13·76	8·86	2·23	0·00	0 31
Carbonic oxide...	23·51	22·24	22·65	28·18	33·64	35·01	41·59
Hydrogen.........	5·82	6 00	5·44	3·82	3·59	1·92	1·42
	18·09	17·13	16·87	12·55	5·20	1·49	11·36

[9] Trav. Scient. 2. p. 314.

TABLE III., B.[10]—COMPOSITION BY VOLUME OF THE GASES OF THE FURNACE AT CLERVAL. *Ebelmen,* A.D. 1848.

Component gases per cent. by volume.	Depth in English feet below the mouth.							
	3¼		9⅝		19⅔		27⅝	
	Depth in metres below the mouth, as stated by Ebelmen.							
	1m		3m		6m		8m 55	At the tymp.
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Nitrogen	57·22	58·56	60·92	60·89	63 04	63·06	61·22	58·17
Carbonic acid ...	12·01	11·95	4·14	4·23	0·49	0·07	0·00	0·93
Carbonic oxide...	24·65	23·85	31·56	31·34	35·05	35·47	37·55	39 86
Marsh-gas.........	0·93	1·33	0·34	0·77	0·36	0 31	0·10	0·25
Hydrogen	5·19	4·31	3·04	2·77	1·06	1·09	1·13	0 79
	16·26	14·50	6·43	6·42	2·31	1·97	4·40	9·60

[10] Trav. Scient. 2. p. 420.

TABLE IV.[1]—COMPOSITION BY VOLUME OF THE GASES OF THE FURNACE AT AUDINCOURT, FRANCE. *Ebelmen.*

Component gases per cent.	At the mouth.	Depth in English feet below the mouth. 11¼	14¼	18	21⅞	26⅜
		Depth in metres below the mouth, as stated by Ebelmen. 3m·33	4m·33	5m·50	6m·67	8m·04
	I.	II.	III.	IV.	V.	VI.
Nitrogen	55·62	54·39	56·07	57·84	57·87	61·61
Carbonic acid ...	12·59	14·46	9·55	7·54	3·81	0·21
Carbonic oxide...	25·24	23·62	28·82	30 03	34·28	36 39
Hydrogen	6·55	7·53	5·56	4 59	4·04	1·79
	19·06	22·03	16·47	12·73	9·94	3·60

[1] Trav. Scient. p. 315.

TABLE V.—COMPOSITION BOTH BY VOLUME AND WEIGHT OF THE GASES OF THE WRBNA FURNACE AT EISENERZ, STYRIA. *Tunner and Richter.*[2]

By Volume.	Depth below the mouth in Austrian feet.[3] 11	17	23	27	34
	I.	II.	III.	IV.	V.
Nitrogen	70·50	71 36	68·81	66·66	66·34
Carbonic acid.....	16·39	17·80	9·60	2·68	11·60
Carbonic oxide ...	13·11	10·89	21·59	30·66	22·06
	6·28	6·29	3·37	0·76	7·85
By Weight.					
	Ia.	IIa.	IIIa.	IVa.	Va.
Nitrogen...........	63·50	60·52	64·90	65·65	62·23
Carbonic acid......	23·56	24·86	14·26	4·15	17·07
Carbonic oxide ...	12·94	14·62	20·84	30·20	20·70

[2] Tunner's Jahrbuch, 9. p. 281. 1860.
[3] I have not considered it necessary to reduce these to English feet, of which 103·71 = 100 Austrian feet.

TABLE VI.—COMPOSITION BOTH BY VOLUME AND WEIGHT OF THE GAS 11 FEET BELOW THE MOUTH OF THE KAISER-FRANZ FURNACE, EISENERZ, STYRIA.

By Volume.		By Weight.	
Nitrogen	69·68	Nitrogen	64 27
Carbonic acid......	17·09	Carbonic acid......	24·62
Carbonic oxide ...	13·23	Carbonic oxide ...	11·11
	7·75		

TABLE VII.—Composition by volume of the gases from the furnace at Seraing, Belgium. *Ebelmen*, A.D. 1848.

Component gases per cent. by volume.	Depth in English feet below the mouth.							
	1		4	9	$9\frac{5}{8}$		$11\frac{1}{3}$	45
	Depth in metres below the mouth, as stated by Ebelmen.							
	0m 304		1m 220	2m 743	3m 048		3m 567	13m 716
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Nitrogen	57·06	56·64	59 64	62·46	61·67	61·15	61·34	54·63
Carbonic acid ...	11·39	11·39	9·85	1·54	1·08	1·13	0·10	..
Carbonic oxide...	28·61	28·93	28·06	33·88	35·20	35 35	36·30	45·05
Marsh-gas.........	0·20	..	1·48	1·43	0·33	0·29	0·25	0·07
Hydrogen.........	2·74	3·04	0·97	0·69	1·72	2·08	2·01	0·25
	18·76	19·38	13·77	3·48	4·03	4·48	3·49	14·96

TABLE VIII.—Composition by volume of the gases of the furnace at Alfreton, England. By *Bunsen and Playfair.*

Component gases per cent. by volume.	Depth in English feet below the mouth.								
	5	8	11	14	17	20	23	24	34
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
Nitrogen	55·35	54·77	52·57	50·95	55·49	60·46	58·28	56·75	58·05
Carbonic acid......	7·77	9·42	9·41	9·10	12·43	10·[illegible]	8 19	10·08	0·00
Carbonic oxide ...	25·97	20·24	23 16	19·32	18·77	19·48	26·97	25·19	37·43
Marsh-gas	3·75	8·23	4 58	6·64	4·31	4·40	1·64	2·33	0·00
Hydrogen	6·73	6·49	9·33	12·42	7·62	4·83	4·92	5·65	3·18
Olefiant gas	0·43	0·85	0 95	1·57	1·38	0·00	0 00	0·00	0·00
Cyanogen	0·00	0·00	0·00	0·00	0·00	0·00	trace	trace	1·34
	11·23	9·41	13·67	10·56	13·04	7·76	10·92	13·68	5·97

Supplementary Details relating to the foregoing Tables.

Table I.[4]—The dimensions of the furnace are not given. Charcoal was the fuel, and it was reported to contain 1·7% of ash and 5% of moisture. The gas was collected on the 28th September from 2 A.M. to 11 P.M. The diameter of the nozzle of the blast-pipe was 26·5 Paris lines (about 2¼ in. English). During the collection of the gas, the pressure of the blast ranged from 16·1 in. to 17·2 in. (nearly the same as English) of water, and from 243° C. to 313° C. The weight of air injected per minute was computed at 10k 432. The average monthly consumption of charcoal per minute was 1k 705, with an average production per minute of 1k 0218 of pig-iron, and an evolution from the ore of 0k 3938 of oxygen, which passed off in combination

[4] Poggendorff's Annal. 46. p. 192, 1839.

with carbon. The foreign matters melted per minute amounted to 4·[illegible]4.

TABLE II.[a]—The furnace was regularly conical from the mouth to [illegible] above the top of the boshes, where it was nearly cylindrical. From the top of the boshes to the top of the hearth it was inversely conical. The dimensions of the furnace were as follow:—Width at the mouth 4 ft. 9 in., at the top of the boshes 7 ft. 3 in., of the hearth 1 ft. 11 in.; height from the mouth to the top of the boshes 1[illegible] ft., from this point to the hearth bottom 1[illegible] ft.; total height 2[illegible] ft.[b] The hearth in the engraving to scale is represented as very shallow, and not more than about 6 in. in depth. The diameter of the nozzle of the blast-pipe was 2¼ in. Rheinland (about 2¼ in. English). During the collection of the gas the mean pressure of the blast was equal to a column of mercury of 14 lines Rheinland (about 1¼ in. English), and the temperature ranged from 2[illegible]° C. to 2[illegible]° C. The charge consisted of a mixture of specular iron ore and magnetic oxide, yielding on the average from 40% to 42% of iron. The ores were partly calciferous and partly siliceous, so that by mixing them in suitable proportions a good slag was formed without the addition of flux. Fir charcoal was used. Grey iron was produced, of which the average weekly

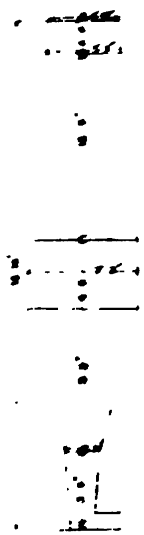

Fig. 77. Baerum, Norway. Scheerer. Charcoal. 775 cubic ft. [illegible] content.

yield was 140 Skeppunds (1 Skeppund Norwegian = 3½ cwts., which would give about 22 tons as the weekly make. 1 Skeppund Swedish = 5·192 to the ton English in the sale of pig-iron and iron ores).

TABLE III., A.—The dimensions of the furnace were as follow:—Width at the mouth $0^m 67$ (2 ft. 2·38 in.), at the top of the boshes $2^m 16$ (7 ft. 1·04 in.), at the bottom of the boshes $0^m 62$ (2 ft. 0·41 in.), at the twyer $0^m 44$ (1 ft. 5·33 in.). Height from the mouth to the top of the boshes $5^m 67$ (18 ft. 7·23 in.), of the boshes $2^m 12$ (6 ft. 11·47 in.), from the top of the boshes to the hearth $3^m 00$ (9 ft. 10·11 in.). The heights above the twyer in English feet are those in Bunsen and Playfair's table; but I am not quite sure that they are estimated exactly according to the dimensions given by Ebelmen. In No. II. column, for example, the height is 25½ ft., which is the vertical height from the mouth to the top of the hearth at the point of junction with the bottom or narrow part of the boshes. But between this point and the twyer is the "ouvrage," of which the height in this furnace was $0^m 44$ (1 ft. 5·33 in.). The distance from the bottom of the "ouvrage" to the mouth $8^m 23$ (27 ft.). The furnace was worked with hot-blast ranging in temperature from 175° C. to 190° C. The diameter of the nozzle of

[a] Poggendorff's Annal. 60. p. 489. 1843.

[b] I have not considered it necessary to give the dimensions in English feet, as they are so nearly the same.

the blast pipe was $0^{m}065$ (2·56 in.). The pressure of the blast was very feeble, and varied from $0^{m}015$ (0·59 in.) to $0^{m}018$ (0·70 in.) of mercury. During the collection of the gases the charge consisted of $0^{m.c.}500$ of charcoal (= 115 kil.), of limestone $0^{m.c.}020$ (= 29 kil.), and of ore $0^{m.c.}160$ (= 287 kil.) to $0^{m.c.}170$ (= 305 kil.). The average yield of pig-iron per charge was $78^{k}10$. For 1 part of pig-iron 1·48 of charcoal and 3·81 of ore were required, all estimated by weight. During September, 1841, the furnace at Clerval produced 61,170 kil. of pig-iron, *i. e.* about 61 tons per week. The pig-iron was almost constantly grey. The gases were collected by means of cast-iron pipes $0^{m}10$ (3·94 in.) in diameter. Tapping occurred every twentieth charge. The approximate composition of the charge of ore and limestone was as follows:—

Water	12·5
Carbonate of lime	21·0
Sesquioxide of iron	39·2
Oxide of manganese	0·7
Silica	20·0
Alumina	6·6
	100·0
Metallic iron per cent.	27·4

Or, the composition may be thus represented :

Metallic iron		27·2
Volatile matter = 33·7%	Oxygen	12·0
	Water	12·5
	Carbonic acid	9·2
Fixed matter = 39·1%	Silica	20·0
	Alumina	6·6
	Lime	11·8
	Oxide of manganese	0·7
		100·0

The charcoal contained 8% of moisture, and was analysed after desiccation at about 150° C. It lost 13·06% in weight by exposure to a white heat.

The composition of the charcoal and of the volatile matter thus evolved is as follows :—

	Carbon.	Volatile Matter.	
Carbon	87·68	3·80	28·7
Hydrogen	2·83	2·83	21·6
Oxygen	6·43	6·43	49·7
Ashes	3·06		
	100·00	13·06	100·0

The gas from the top of the boshes was collected through a cast-iron tube passing through the wall of the furnace; the gas had a nauseous odour somewhat like that of arsenic. The gases taken from the lower parts of the furnaces both of Clerval and Audincourt had constantly this odour. The gas on ignition produced a blue flame, with red edges, of great intensity.

Table III., B.—The accuracy of Ebelmen's analysis of the gases from

the furnace at Clerval having been questioned, he entered upon another investigation at the same Iron-works in October, 1848. The furnace, however, had been considerably altered in dimensions, and it was worked with cold-blast. Width at the mouth $0^{\mathrm{m}}56$ (1 ft. 10·05 in.), at the top of the boshes $2^{\mathrm{m}}50$ (8 ft. 2·43 in.). Height from the mouth to the top of the boshes $6^{\mathrm{m}}67$ (21 ft. 10·60 in.), of the boshes $2^{\mathrm{m}}03$ (6 ft. 7·92 in.), of the "ouvrage" $0^{\mathrm{m}}40$ (1 ft. 3·75 in.), of the hearth $0^{\mathrm{m}}40$ (1 ft. 3·75 in.), total height of the furnace $10^{\mathrm{m}}00$ (32 ft. 9·70 in.). At the junction of the upper part with the boshes the furnace was cylindrical to the height of $0^{\mathrm{m}}50$ (1 ft. 7·69 in.). The diameter of the nozzle of the blast pipe was $0^{\mathrm{m}}063$ (2·48 in.), and the twyer was $0^{\mathrm{m}}09$ (3·54 in.) in width by $0^{\mathrm{m}}10$ (3·94 in.) in height. The pressure of the blast was equal to $0^{\mathrm{m}}033$ (1·30 in.) of mercury. The charge consisted of $0^{\mathrm{m.c.}}500$ (= 115 kil.) of wood charcoal; of $0^{\mathrm{m.c.}}165$ (= 295 kil.) of ore (similar to that used in 1841); and of $0^{\mathrm{m.c.}}010$ (= 15 kil.) of limestone. Of these charges 32 were worked off every 24 hours. Tapping took place after every 20 charges, and produced 1800 kil. of dark grey pig-iron, so that the daily yield was about 2800 or 2900 kil. of pig-iron. The gases were utilized and taken off from an annular space at the top of the furnace round a cylinder of cast-iron which received the charge. The analyses of the gases were in this case made in Regnault and Reiset's eudiometer. In No. I. column the gas operated upon was obtained from the pipe, which conveyed the waste gas away as above described. The gas of which the composition is given under the columns V., VI., VII., was obtained from openings through the walls of the furnace. In the case of No. VII. the orifice was $1^{\mathrm{m}}05$ (3 ft. 5·34 in.) above the twyer; it escaped with force, and burned in the air with a white flame and thick smoke of oxide of zinc. Ebelmen sought for cyanogen in the gases from Nos. V. to VIII., but failed to detect its presence.

TABLE IV.—The investigation was made in October, 1841. The dimensions of the furnace were as follow:—Width at the mouth $0^{\mathrm{m}}66$ (2 ft. 1·98 in.), at the top of the boshes $2^{\mathrm{m}}33$ (7 ft. 7·73 in.), at the "ouvrage" $0^{\mathrm{m}}45$ (1 ft. 5·72 in.). Height from the mouth to the top of the boshes $8^{\mathrm{m}}67$ (28 ft. 5·34 in.), total height $11^{\mathrm{m}}00$ (36 ft. 1·07 in.). The blast was heated to 250° C. The pressure varied from $0^{\mathrm{m}}070$ (2·76 in.) to $0^{\mathrm{m}}074$ (2·92 in.) of mercury. The charge consisted of 92 kil. of charcoal, 115 kil. of wood (cut into pieces $0^{\mathrm{m}}15$ (= 5·91 in.) in length, and not previously prepared in any manner), 18 kil. of braize, 33 kil. of limestone, 77 kil. of forge cinders broken up, and 258 kil. of ore. The average yield per charge was $114^{\mathrm{k}}2$ of pig-iron.

The charge without fuel was approximately composed as follows:—

Water	9·7
Carbonate of lime	22·0
Sesquioxide of iron	26·5
Protoxide of iron	15·5
Oxide of manganese	0·9
Silica	20·0
Alumina	5·4
	100·0

Or, the composition may be thus represented:

Metallic iron		30·4
Volatile matter =31·0%	Oxygen	11·6
	Water	9·7
	Carbonic acid	9·7
Fixed matter =38·6%	Silica	20·0
	Alumina	5·4
	Lime	12·3
	Protoxide of manganese	0·9
		100·0

The temperature was very low in all the upper part of the furnace, so much so that Ebelmen found by direct experiment that pieces of wood, which had remained at the depth of 3 metres (9 ft. 10·11 in.) during $1\frac{3}{4}$ hour, on being taken out of the furnace had precisely the same appearance as when they were put in. Wood which had remained during $3\frac{1}{4}$ hours at the depth of 4 metres (13 ft. 1·48 in.) was completely carbonized, the ore had become magnetic and lost the whole of its combined water. The gas was collected in the same manner as at Clerval, except that in No. VI. column, which was procured from an opening through the walls of the furnace. The gas No. II. contained a large amount of the products of the distillation of wood. In collecting the gas No. III. neither water nor tar was deposited in the glass tubes. The gas No. VIII. burned with a white flame, and had the same nauseous odour as the gas from the boshes of the furnace at Clerval; the gas taken at higher elevations burned with a blue flame.

TABLE V.—The furnace was working on *white* iron; it was circular in section in every part, and its dimensions were as follow:—Width at the mouth, $2\frac{1}{4}$ ft. (Vienna feet. I have not given these dimensions in English feet, as the differences in a large furnace of this kind are not material); at the top of the boshes, 8 ft.; at the hearth-bottom, $5\frac{1}{4}$ ft. The interior of the furnace is conical to 1 ft. above the top of the boshes, when it becomes cylindrical; and from the top of the boshes, *i.e.* the bottom of the cylindrical portion to the hearth, its form is that of a regular inverted cone, so that there is no line of demarcation between the boshes and the hearth. Height from the mouth to the top of the boshes, $25\frac{1}{2}$ ft.; from the top of the boshes to the twyers, 8 ft. 10 in.; and from the twyers to the hearth-bottom, 1 ft. 8 in.: total height, 36 ft. There were three twyers, 1 ft. 8 in. above the hearth-bottom, one on each side, with a blast-pipe $2\frac{6}{12}$ in. in diameter; and one at the back, with a blast-pipe $1\frac{4}{12}$ in. in diameter. The temperature of the blast was 200° C., and the pressure varied from $1\frac{6}{12}$ in. to $1\frac{9}{12}$ in. of mercury. An iron cylinder 6 ft. 6 in. in depth was inserted in the mouth, and from the space included between the outside of this cylinder and the corresponding part of the internal walls of the furnaces the waste-gases were taken off through an iron tube 1 ft. 4 in. in diameter. The fuel was "soft" (*i. e.* light) charcoal; the iron-producing material was calcined spathic ore and cast-iron scrap, and the flux was "grauwacke-schist." The charge

consisted of 19¼ (1 c. f. = 1·115 English) cubic feet of charcoal, 383 lbs. of ore, 8 lbs. of scrap, and 20 of flux. The yield of the calcined ore was 50 %. There were 143 charges per day of 24 hours, producing on the average 280 centners (1 centner = 100 lbs., or 123·46 lbs. avoirdupois. 1 lb. = 1·2352 lb. avoirdupois) of white pig-iron of a radiated structure (weissstrahlig), *i.e.* for 100 lbs. of pig-iron 70 lbs. of charcoal, or by measure 9·9 cubic feet. The gas was collected by means of wrought iron tubes 1 in. in external, and ½ in. in internal, diameter. The pressure of the gas on escaping from the top of the furnace was about half that of the blast, and when the latter varied, there was also a corresponding variation in the former. Numerous observations were made upon the variations in the pressure of the gas escaping at the mouth consequent on the formation of slag "noses," on the twyers and other conditions, and also upon the temperature of the furnace from top to bottom; pyrometric alloys of lead and silver, silver and gold, and silver and platinum, being used for this purpose. Tunner remarks that the eudiometer employed in these analyses was not sufficiently finely divided to admit of the measurement of the small volumes of hydrogen and marsh-gas. But, as in the analyses of preceding observers, the united volumes of these two gases amounted to not less than 5 % or 6 % of the whole, their proportion can scarcely be designated as small.

Table VI.—The gas was obtained from a furnace working on *grey* iron at the village of St. Stephen. Width at the mouth, 2 ft. 8 in.; at the top of the boshes, 9 ft. 6 in.; and at the bottom of the hearth, 3 ft. 6 in. Height from the mouth to the top of the boshes, 30 ft.; from the bottom of the boshes to the twyers, 8 ft.; and from the twyers to the hearth bottom, 2 ft.: total height, 40 ft. The form of the interior was similar to that of the last furnace, except that the cylindrical portion forming the upper part of the boshes was 4 ft. high. There were two twyers, one opposite the other. At the time of collecting the gas the temperature was 200° C., and the pressure ranged from $\frac{8}{12}$ in. to 1 in. of mercury. The waste-gases were utilized, and taken off at the top. The charge consisted of 15¼ cubic feet of light charcoal, from 310 lbs. to 320 lbs. of ore, consisting half of roasted spathic ore and half of argillaceous ore, and 15 lbs. of limestone. The yield of the ore ranged from 35 % to 36 %. There were on the average 74 charges per day of 24 hours. For 100 lbs. of grey iron, 14 cubic feet, or from 95 lbs. to 100 lbs. of charcoal were consumed.

Table VII.—The gas was collected in September, 1848, from No. 6 furnace, working with coke, at the Seraing Iron-works, near Liége, in Belgium. The dimensions of the furnace were as follow: Width at the mouth, $2^m 74$ (8 ft. 11·88 in.); at the top of the boshes, $4^m 57$ (14 ft. 11·93 in.); at the top of the "ouvrage," $1^m 09$ (3 ft. 6·94 in.); between the twyers, $0^m 91$ (2 ft. 11·82 in.). Height from the mouth to the top of the boshes, $8^m 13$ (26 ft. 8·08 in.); of the boshes, $4^m 52$ (14 ft. 9·96 in.); of the "ouvrage," $1^m 32$ (4 ft. 3·97 in.); of the hearth, $0^m 81$ (2 ft. 7·89 in.): total height of the furnace, $15^m 24$ (48 ft.). There were two twyers. The quantity of air blown into the furnace per minute

was 122 cubic metres, at a pressure of $0^{m}05$ (1·97 in.) of mercury. The temperature of the blast was 100° C. The charge consisted of raw ore 650 kil., of mill-furnace cinders 650 kil., of limestone 450 kil., and of coke 2 cubic metres = 800 kil. Tapping occurred every 12 hours, and produced 8500 kil. of white slightly crystalline pig-iron, suitable for puddling without further treatment. The yield of the ores was 42 %, with a consumption of 1·5 by weight of coke for 1 of pig-iron, *i e.* 133 of carbon for 100 of pig-iron. When the furnace was on grey foundry iron, the consumption of coke amounted to 1·8 or 2 for 1 of pig-iron. The gas No. VIII. was procured from an opening through the walls of the furnace; in every other case it was collected by means of wrought iron pipes, $0^{m}03$ (1·18 in.) in diameter. The gas No. III. ignited spontaneously in the air. The gas No. VIII., from about $0^{m}61$ (2 ft. 0·01 in.) above the twyers, was accompanied with copious white smoke, which, according to Valérius, contained cyanide of potassium. Ebelmen was unable to detect in this gas either carbonic acid, sulphuretted hydrogen, or cyanogen.

The coke contained on the average 91 % of carbon, 3 % of water and volatile products, and 6 % of ashes. The composition of the charge may, according to Ebelmen, be thus represented:—

	kil.				kil.
Coke	800	corresponding to pure carbon			728
Limestone	450	Carbonic acid	200	Carbon	54
		Lime	250	Oxygen	146
Ores and cinders 1300 kil.		Cinders 650	containing	Oxygen of protoxide of iron	78
		Ore ... 650		Oxygen of sesqui-oxide of iron	117
Or, Total carbon				782	
Oxygen		of the limestone	146		
		of the cinders	78	341	
		of the ore	117		

Ebelmen remarks that "if the analyses of the gases of the mouth well represented the mean composition at the exit from the furnace, the weights of the oxygen and carbon given above ought to be in the same relation as the carbon and oxygen of the gases, on deducting from this latter the proportion corresponding to the nitrogen contained in the gas. Now, the number which represents the oxygen at the mouth is equal to 45·0; and on deducting from this 26·3, which corresponds to the nitrogen, 18·7, the relations between the oxygen and carbon are 18·7 to 35·2 in volume, and 18·7 to 26·4. The relation here is about 3 to 4, whilst it ought to be below $\frac{1}{2}$ after the number given above." Ebelmen, therefore, concluded that the analyses of the gases from the mouth do not represent the mean composition of the gaseous current at its exit. The gas operated on was taken off from a very small portion of the horizontal section of the furnace—only 0·0001 of the area of the mouth; the velocity of the current is not the same in every part, being greatest along the sides, and rapid chemical actions moreover occur there: these considerations in Ebelmen's judgment suffice to explain the discordance in question. The sectional area of the tubes employed by him at Clerval and Audincourt was equal to $\frac{1}{30}$ of that

of the mouth, and the current escaped with great velocity, so that the analysis of the gases of this current should accurately give the mean composition of the corresponding gaseous section.

TABLE VIII.—*Bunsen and Playfair's experiments.*[7]—They were made at Mr. Oakes' Iron-works, Alfreton, Derbyshire. Fig. 78 is a vertical section of the interior of the furnace. The diameter of the blast-pipe was 2½ in. The pressure of the blast was equal to a column of mercury of 6·75 in., and the temperature was 330° C. (626° F.). The fuel was raw coal, yielding about 67½ % of coke. The ore consisted of calcined argillaceous ironstone and the flux of limestone. The limestone was broken in pieces about as large as the fist, but the coal and ironstone were thrown in in lumps, not unfrequently exceeding 20 lbs. in weight. The composition of the coal, calcined ore, and limestone, was as follows:—

Coal.		Calcined ore.		Limestone.	
Carbon	74·98	Silica	25·77	Lime	54·4
Hydrogen	4·73	Sesquioxide of iron[8]	60·24	Magnesia	0·6
Oxygen	10·01	Alumina	6·58	Alumina	0·8
Nitrogen	0·18	Lime	3·51	Carbonic acid	42·9
Water	7·49	Magnesia	3·19	Moisture and loss	1·3
Silicates	2·61	Potash	0·74		
Potash	0·07	Manganese	traces.		
	100·07		100·03		100·0

In producing 140 lbs. of pig-iron, were required 390 lbs. of coal, 420 lbs. of calcined ore, and 170 lbs. of limestone. The quantity of ore smelted every 24 hours was 33,600 lbs., and the coal consumed 31,200 lbs.

The apparatus for collecting the gases consisted of a system of wrought iron tubes, 26 ft. long and 1 in. in diameter. It was formed of pieces 5 ft. long, screwed together so as to be air-tight. It was suspended vertically by a chain passing over a block fixed to a stout wooden upright, and fastened by chains round the furnace. It was necessary to play water upon this support occasionally, to keep it from burning. A leaden pipe was inserted into the top of the tube in order to conduct the gases. The tube was allowed gradually to descend along with the contents of the furnace, and its depth was indicated by white marks at the distance of 1 ft. It sank at the rate of 3 ft. in an hour during the first part of the experiment, but more slowly afterwards. The gases were collected in glass tubes, 4 in. long and ¾ in. wide, which were drawn out at both ends and connected with each other, as well as with the lead tube, by caoutchouc joints. Owing to the pressure of the gas, which often amounted to several inches of water, the tubes could not be hermetically sealed while in connection with the lead pipe, and it was, therefore, necessary to heat them so as to expand the gas to a certain extent, then to tie the caoutchouc

[7] Report to the British Association, at Cambridge, on the Gases evolved from Iron Furnaces, with reference to the Theory of the Smelting of Iron. 1845. pp. 142-186.

[8] It is stated that the protoxide is converted into sesquioxide of iron by calcination; but this is only in part correct.

joints, and not to seal the tubes hermetically until they had become sufficiently cool to prevent any small explosion during the melting of the glass. Gas was collected in all regions below and above what is termed the zone of fusion, where the temperature was so high as either to soften or melt the tubes completely. But below this zone, where a still higher temperature prevails, gas was collected by boring through the front above the tymp and inserting an iron tube.

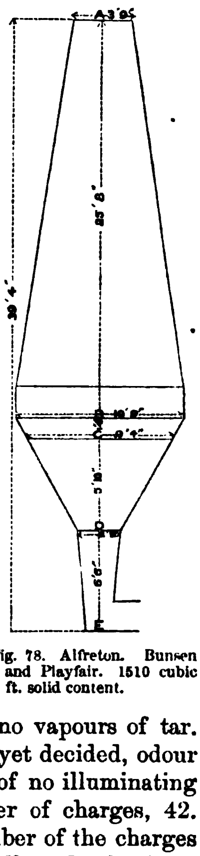

Fig. 78. Alfreton. Bunsen and Playfair. 1510 cubic ft. solid content.

I. The gas had a peculiar odour, different from that of coal-gas, but very similar to that of acrolein; it burned with a yellowish red flame, and was not accompanied with brown vapours of tar. II. The blast had been interrupted during an entire hour previous to the experiment, but the gas was not collected until the furnace had been for some time in tranquil action. The flame and odour were exactly the same as in Exp. I. Number of charges, 14. III. The gas was accompanied by vapour of tar, and had the odour of coal-gas. The flame was clear yellow, and highly luminous. Number of charges, 23. IV. The odour of the gas was ammoniacal and tar-like; vapours of tar were visible; the flame was yellow, but only feebly luminous. Number of charges, 26. V. The gas had a peculiar, tar-like odour; there were no vapours of tar; and the flame was yellow and slightly luminous. Number of charges, 32. VI. The gas had an ammoniacal odour, and burned with a pale blue flame. There were no vapours of tar. Number of charges, 38. VII. The gas had a slight, yet decided, odour of cyanogen, and burned with a pale blue flame "of no illuminating power." There were no vapours of tar. Number of charges, 42. VIII. The gas had the same character, and the number of the charges was the same as in Exp. VII. IX. This gas was collected 6 ft. above the hearth-bottom, and 2 ft. 9 in. above the twyer: the presence of cyanogen was detected by its odour, and by the purple colour of the flame. On the assumption that marsh-gas was present instead of cyanogen, the composition of the gas, deduced from the analytical data, would have been as follows:—

Nitrogen	59·39
Carbonic oxide	38·33
Marsh-gas	1·79
Hydrogen	0·49
	100·00

But it is contended that marsh-gas could not possibly exist in this part of the furnace, because it is alleged that this gas can only proceed from the dry distillation of the coal, and that carbonization must be completely effected at a higher elevation. Yet only about 10 ft. above the bottom, or 24 ft. below, the mouth of the furnace, not less than

2·35 p. c. of marsh-gas was found; and this is regarded as a proof that the coking of the coal continues even to this depth. The conclusion as to the impossibility of the existence of marsh-gas so low down as 2 ft. 9 in. above the tuyere may be extremely probable, but it is certainly not established beyond question. It should be stated that Bunsen ascertained that marsh-gas can neither be formed by the direct combination of hydrogen with carbon, nor by the action of the vapour of water on incandescent carbon.

It is concluded that the distillation of the coal was most active at the depth of 14 ft., because in the gas from this part of the furnace the olefiant gas, marsh-gas, and hydrogen were at a maximum, and these gases are only evolved from coal under the influence of a high temperature. Bunsen and Playfair observe that the presence of tarry vapours at the depth of 14 ft., and even 17 ft., and their absence from the upper part of the furnace, prove that they suffer decomposition in traversing the superincumbent red-hot coal. The water also contained in these vapours must be decomposed in like manner; and this fact is urged in explanation of the irregularity in the proportions between the carbonic acid and the carbonic oxide.

Ebelmen has commented as follows upon the preceding observations respecting the disengagement of tarry vapours at a considerable depth in the furnace: "It appears to me impossible to admit, with MM. Bunsen and Playfair, that if tar is only found in the gases collected between the depths of 4m 267 and 5m 179, it is necessary to attribute it to the decomposition suffered by the vapours of this tar in traversing *the upper incandescent layers of coal*. If, indeed, there exist above the depth of 4m 267 an incandescent zone, it would be unintelligible how the coal should reach this depth of 4m 267 without having lost at least a large portion of its tar, and how it can traverse this zone, where the decomposition of tar occurs, in order to arrive at a greater depth where the tar is only disengaged. What is infinitely probable is, that the distillation of the coal really only commences at the depth of 4m 267, and the cold ore and fuel, which occupy the upper part of the shaft [*la cuve, i. e.* the part above the boshes], act as apparatus for condensing the vapours of tar."[*] Bunsen and Playfair state that at the depth of 11 ft., which is sensibly less than 4m 267, the gas was accompanied by vapour of tar.

With regard to Ebelmen's supposition concerning the condensation of tar on the cold materials near the mouth, from what I have seen of blast-furnaces in operation, I should think it difficult for tar to remain long in that position in any but a vaporous state; and equally difficult to conceive that tar would only begin to be formed at the depth of 4m 267. The point, however, raised by Ebelmen is a fair one; but it seems to be met by the fact to which Bunsen and Playfair direct attention, namely, that the coal was thrown in in large lumps, and that while the external portion was coked the interior might have been only slightly altered.

* Trav. Scient. 2, p. 410.

Observations on the foregoing Analytical Results.

Let us suppose that the solid materials introduced into the blast-furnace consist of pure oxide of iron and pure carbon, and that combustion is supported by dry atmospheric air; then it is evident that in the ascending gaseous current the relation between the nitrogen and the oxygen, in whatever state of combination the latter may be, will indicate precisely the degree of reduction effected. If no oxide of iron were present, that relation would be the same from the twyers to the mouth. But in the case supposed oxide of iron is present, and the proportion of oxygen, consequently, in relation to the nitrogen will increase from that part of the furnace in which the iron is completely reduced up to that part where reduction commences, or, in other words, from the bottom to the top of the zone of reduction. In actual practice the simple relation in question is not maintained, because no fuel is ever employed free from oxygen, and the whole of this passes into the ascending gaseous current, together with the oxygen existing in the carbonic acid of the limestone used as flux.

Moreover, atmospheric air is not only always moist, but is subject to considerable variation with respect to degree of moisture; and, hence, there will necessarily be a corresponding variation in the oxygen of the gaseous current. Again, coke and coal contain between 1 % and 2 % of nitrogen, and when either of these is used as fuel, the atmospheric air blown in will not be the only source of nitrogen in the gas evolved from the mouth of the furnace. Still, the addition of nitrogen from these sources is comparatively so small that practically it may be disregarded.

In atmospheric air the relation by volume between the nitrogen and oxygen is 100 : 26·26. In the preceding tables it is easy to find the relation by volume between the nitrogen and the oxygen present in the two states of combination with carbon, namely, as carbonic acid which contains its own volume of oxygen, and as carbonic oxide which contains only half its volume of oxygen. The sum, therefore, of the volume of the carbonic acid and half the volume of the carbonic oxide represents the volume of oxygen which would exist if free, as in atmospheric air.

In all the preceding experimental investigations concerning the composition of the gaseous current of blast-furnaces, there is one source of error which should particularly be borne in mind. The gas from any given furnace was collected at successive intervals; and it is doubtful whether any method could have been adopted for collecting it simultaneously at different depths, except by the insertion of tubes through the sides of the furnace, which would have involved much additional expense, and which might not, after all, have yielded perfectly satisfactory results, as the gas from the centre, owing to variation in the velocity of the gaseous current in different parts of the same transverse sectional area, may not have the same composition as that near the sides. Now, identity of conditions cannot be ensured even in the same furnace for an hour, much less for a day, so that the gas

collected at intervals, however short, from exactly the same part of the furnace, working with the same charge, may not have the same composition. It would, therefore, be unreasonable to expect that the observations recorded in any one of the foregoing tables should be in exact accord with any general deduction from the whole.

Assuming carbonic oxide to be the essential agent in reduction, the succession of chemical changes which takes place in the blast-furnace from the mouth downwards might have been certainly predicated on theoretical grounds; and, as far as I am able to judge, the importance, whether in a scientific or practical point of view, of the results of the preceding analytical investigations has been somewhat overestimated. It is obvious that the temperature of the blast-furnace must increase downwards to the twyers; and if there had been any doubt on the point, it is removed by the direct experiments which have been made on the subject, and the results of which will be subsequently stated in detail. Temperature, carbonic oxide, and incandescent carbon explain all the phenomena of the blast-furnace. The iron ore in its descent in the furnace undergoes the following succession of changes: loss of hygroscopic water, and—if it be a carbonate—loss also of carbonic acid; loss of oxygen, or reduction; carburization of the reduced iron, and fusion. The last two changes probably occur *pari passu*. The furnace has accordingly been divided into four corresponding zones—the zone of preparation, the zone of reduction, the zone of carburization, and the zone of fusion. The limits of these zones must obviously be subject to considerable variation, and will specially depend on the form of the interior of the furnace,—on the dimensions of the furnace,—on the nature of the fuel,—on the quality of the ore with regard to reducibility,—on the burthen, *i.e.* the proportion of ore to fuel,—on the size of the materials constituting the charge, especially of the ore,—on the amount of air blown in in a given time, or, in other words, on the driving of the furnace,—on the temperature of the blast,—and on other conditions in a minor degree. The term zone, as applied to the blast-furnace, means a definite horizontal sectional area; but it does not follow that the same conditions as to temperature, velocity of ascending gaseous current, etc., should prevail in every part of such area. Indeed, in some instances this is certainly not the case. Even in the same furnace, with the same charges of ore, fuel, and flux, these zones of specific action may not have precisely the same position at different times, as it has been hitherto found impossible to ensure uniform results from any furnace, though working under apparently identical conditions. With all the elements, then, of variation above-mentioned, it seems almost affectation to prescribe, as is sometimes done, the limits of these zones in a blast-furnace with as much precision as the zones of the earth are represented on geographical maps.

In the preceding Tables attention should specially be directed to the decrease in the proportion of oxygen relatively to the nitrogen in atmospheric air in the ascending gaseous current at considerable depths in the furnace. Now, such a decrease implies an abstraction of oxygen

from the gaseous current and its fixation in a solid state of combination, or an evolution of nitrogen in sensible quantity from the solid contents of the furnace; but I cannot understand how either of those results should occur. In only one instance is the proportion of oxygen stated to be actually less relatively to the nitrogen in atmospheric air, and that is in the third column of Table I. In Tables II., III. A., IV., V., the relative proportion of oxygen increases upwards from the last column but one in each Table. In Table I. of Bunsen's results at Veckerhagen and in Table VIII. of Bunsen and Playfair's results at Alfreton the irregularity in the relative proportion of oxygen through a considerable extent is remarkable, and, as it seems to me, difficult to explain. I may here at once avow that there is such an apparent want of accord between many of the results in these various Tables that I have failed in attempting to elicit from them any satisfactory general expressions, as might reasonably have been anticipated. I must, therefore, leave the reader to examine each Table for himself and draw his own inferences therefrom.

According to the observations of Ebelmen (see Tables III. A. and III. B.) the gas in the immediate vicinity of the twyers contains a larger proportion of oxygen in relation to nitrogen than exists in atmospheric air; and at a slight distance above that the proportion decreases. Tunner and Richter also arrived at the same result. In Table VIII. of Bunsen and Playfair's results, the proportion of oxygen relatively to the nitrogen decreases and increases in a strange manner upwards from the depth of 24 ft. below the mouth. Now, accepting these data as correct, it follows necessarily, that, even in this part of the furnace, oxygen must be liberated from the descending solid materials, unless we admit that nitrogen is abstracted from the air blown in and enters into a state of solid combination, such, for example, as that in the cyano-nitride of titanium. But there is certainly as yet no proof of the formation of any solid compound of nitrogen in sufficient quantity to account for the comparatively large excess of oxygen in question. The only way, then, in which that excess can be explained is by the reduction of some oxidized substance or other. Ebelmen concludes that the oxygen is derived from the oxide of iron in combination with silica in the slag; and, if this be so, the so-called zone of fusion is in reality also a zone of reduction.[1]

Ebelmen supposes oxidation to occur in front of the twyers of some of the reduced iron, that the resulting oxide of iron passes into the slag in the state of silicate, and that subsequently reaction will necessarily take place between the oxide of iron so formed and the carbon of the pig-iron or the fragments of charcoal mixed with the slag, with, of course, the evolution of carbonic oxide.[2]

Ebelmen remarks, "the pasty matters which coat the lining of the 'ouvrage' (*i. e.* the part between the top of the hearth and the twyers) contain silicate of iron, which is reduced by the contact of charcoal with the formation of carbonic oxide, so that the gases issuing from an

[1] Op. cit. p. 335. [2] Op. cit. p. 371.

orifice pierced in the lining are richer in carbonic oxide than the gaseous column which circulates in the centre of the 'ouvrage.'"[3] This, however, appears to be only conjecture.

Ebelmen does not state the composition of the pig-iron made during the course of his experiments; but it was, doubtless, not free from silicon. The reduction of silicon by the joint action of carbon and iron requires a very high temperature, such as exists in the vicinity of the twyers; and it seems, therefore, reasonable to infer, that the excess of oxygen may, at least in part, be due to such reduction of silicon. In some of the English furnaces working with coke and siliceous hæmatites, pig-iron containing as much as 3%, 4%, or a still higher percentage of silicon, is not unusual; and 1 part by weight of silicon would correspond to somewhat more than the same weight of oxygen, the exact relation being 22·22 : 24. Hence, in the production of this richly siliceous pig-iron the amount of oxygen evolved and added to that of the atmospheric air blown in through the twyers would not be inconsiderable.

It now remains to consider the other statement of Ebelmen above referred to, namely, the abstraction of oxygen from the ascending gaseous current at a short distance above the twyers. This seems to be only intelligible on the supposition that oxidation takes place, and that the oxygen therein contained becomes fixed in the descending solid, or rather liquid, materials of the charge. The matter so oxidized and fixed can only be reduced iron, and the oxygen must be derived from the air either directly or indirectly from the carbonic acid formed. It is not a little puzzling to understand how within such a limited space oxidation and reduction should thus alternately occur. We may, indeed, speculate on this point, but speculation will be vain without the aid of further experimental evidence. It would be well, however, first to settle the question whether oxidation of iron does sensibly occur in this part of the furnace, as Ebelmen supposed. He founded upon this supposition the following practical deduction: "If we compare," he writes, "two kinds of fuel, which act with different rapidity upon air and carbonic acid, such as coke and charcoal, it is very plain that it will be necessary to increase the mass of the least combustible of the two, relatively to that of the ore, in order that oxidation of the iron should not take place to a greater extent in one case than in the other. Thus experience has proved that, on the average, twice as much coke [by weight] is required as charcoal to produce in the blast-furnace pig-iron of the same amount and of the same quality. In the same manner may be explained the difference of consumption of the same furnace, working always with the same fuel, according as it is desired to produce different qualities of pig-iron. Thus much more charcoal is consumed in order to obtain grey pig-iron than white."[4] There is no doubt about this fact, though there may be much as to the correctness of Ebelmen's explanation of it.

In the foregoing discussion I have ignored the effect which might

[3] Op. cit. p. 359. [4] Op. cit. 2, p. 372.

be due to the aqueous vapour of the blast; because the actual amount of this vapour, under ordinary conditions, can hardly be sufficient to account for any sensible change in the relations existing between the oxygen and nitrogen of the ascending gaseous current. I have also disregarded the amount of oxygen which may proceed from the reduction of alumina, lime, etc., as the proportions of aluminium, calcium, etc., which have been found to exist in any description of pig-iron, are so small as to be practically insignificant.

Theoretical considerations founded on principles long established by experiment, as well as the data presented in the foregoing tables, clearly point to carbonic oxide as the great agent of reduction in the blast-furnace. We know that oxide of iron is readily and completely reduced by the action of this gas even at a red heat, with the formation of carbonic acid. But, as incandescent carbon is present in the blast-furnace, the carbonic acid resulting from reduction is immediately converted by contact with this carbon into carbonic oxide, a considerable amount of heat being thereby abstracted and rendered latent. However, loss of heat from this cause may in a certain degree be compensated for by the heat developed in the reduction of the oxide of iron by the incandescent carbon. That heat is so developed may be certainly inferred from the fact that iron during oxidation evolves a much smaller number of units of heat than would be evolved by the combustion of carbon with the same quantity of oxygen, provided carbonic acid be the product.

There are several points connected with the actions occurring in the blast-furnace, which are so obvious as scarcely to deserve mention, and to which, nevertheless, it appears to me, some writers have given undue prominence. Thus, we need hardly be informed that the vaporization of water and the liberation of the carbonic acid from the limestone used as flux will tend to diminish the temperature of that part of the furnace in which they take place. Nor do we require to be specially reminded, that where the calcination of the limestone is effected, there will be an increase in the proportion of carbonic acid, and, consequently, of oxygen in relation to the nitrogen in the gaseous current.

Production of Cyanogen in the blast-furnace.—In 1835 my friend, Mr. John Dawes, formerly of the Bromford Iron-works, near Birmingham, inserted in the specification of a patent for improvements in the manufacture of iron, a claim for the collection of cyanide of potassium from iron-smelting furnaces by means of a pipe introduced into the furnace near the twyers.[5] But Desfosses so long ago as 1826 published the fact that cyanide of potassium was formed in very notable quantity by passing nitrogen over charcoal heated to redness.[6] Doubts were however entertained on the point, on the ground that the charcoal upon which he operated might not have been free from nitrogen. Many years afterwards Fownes repeated the experiment of Desfosses, replacing common

[5] A.D. 1835. December 9. No. 6948. Abridgments of Specifications relating to the Manufacture of Iron and Steel, p. 39.

[6] Ann. de Chimie et de Phys. 38. p. 158. 1826. (Extracted from Journ. de Pharmacie, t. XII.)

wood charcoal by that of sugar, and still obtained cyanide of potassium, since which the correctness of the original statement of Desfosses has been regarded as fully established.

In 1842 Zinken and Bromeis published a notice of the occurrence of cyanide of potassium in an iron-smelting furnace at Mägdesprung, which had been blown out, and in which charcoal had been used as fuel.[7] In the hearth was found a quantity of charcoal impregnated with metallic lead and saline matter. It was left for four months in water, when it was completely disintegrated, forming a jelly-like mass containing 4-sided tabular crystals and evolving a strong odour of ammonia. Bromeis analysed this mass and detected in it free potash, carbonate, silicate, manganate and cyanate of potash, cyanide and ferrocyanide of potassium, the latter constituting the crystals abovementioned; and he concluded that the cyanogen was produced by the direct combination of the nitrogen of the air, under the influence of pressure and a very high temperature, with the carbon of carbide of potassium.

In 1843 Redlenbacher published an account of the formation of cyanide of potassium in considerable quantity at the Mariazell iron-smelting furnace in Styria.[8] This furnace was worked with a "closed breast" and with hot-blast, of which the temperature occasionally reached 350° C. Three saline products were obtained from this furnace, termed white, black, and grey salt. There was a "light-hole" (Lichtloch) in the fore-part of the furnace, through which flame was allowed to escape during the night for the purpose of illumination. The white salt was collected under the "light-hole," where it solidified in drops. The black salt was deposited in the pipes which carried off the waste gases, and appeared to result from the condensation of the bluish smoke, which escaped from the mouth of the furnace when worked with hot-blast. The grey salt was detached from above the "light-hole." The white salt, after having been fused in a porcelain crucible, was applied commercially in electro-gilding. It is described as "consisting of a white, yellowish, reddish, botryoido-reniform saline mass in stone-like drops." It contained no chlorine, and had all the properties of a mixture of cyanide of potassium and cyanate of potash. It was contaminated with metallic iron, carburized iron, charcoal powder, and carbonate of potash. Both the black and the grey salts only differed from the white in containing larger proportions of foreign matter.

Bunsen and Playfair, as we have seen, found a sensible amount of cyanogen in the gases from the lower part of the Alfreton furnace; and they also collected from the same furnace cyanide of potassium in considerable quantity.[9] They bored a hole over the "front" of the furnace 2 ft. 9 in. above the level of the twyer. Gas immediately issued from it, which burned with a highly luminous yellow flame,

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[7] Ueber die Bildung von Cyanverbindungen in den Producten des Mägdesprunger Hohofens; vom Oberbergrathe Zinken zu Mägdesprung und Dr. C. Bromeis zu Cassel. Poggend. Annalen, 55, p. 89. 1842.

[8] Annal. d. Chem. u. Pharm. 47. p. 150. 1843.

[9] British Assoc. Rep. ante cit. p. 182.

producing copious white vapours. An iron pipe was inserted in this hole without allowing it to pass into the furnace, and the volatile products which escaped from it under a pressure of several feet of water were collected. These products contained so much cyanide of potassium, that special precautions were necessary to avoid its poisonous influence. Although the iron pipe was 22 ft. long, yet the amount of cyanide of potassium carried along with the gas was so great as in a very short time to fill glass tubes $\frac{1}{4}$ in. in diameter. The free end of the pipe was connected with an empty Wolf's-bottle, to which another containing water was attached, so that the gas had to pass through a layer of water 4 in. in depth. The first bottle became quickly filled with a rich white sublimate of dry cyanide of potassium, while the water in the second became a tolerably concentrated solution of the same substance. It was ascertained that 21,933 cubic inches of gas were charged with 0·8944 gramme of cyanide of potassium in mechanical suspension; and it was computed that 224·7 lbs. of cyanide of potassium were generated daily in the Alfreton furnace, 100 parts of coal yielding 0·778 of the salt.

The iron pipe when withdrawn from the furnace was found to be encrusted externally with melted cyanide of potassium, which speedily deliquesced in the air. On bringing the pipe in contact with water, a considerable quantity of hydrogen was evolved, which was attributed to the presence either of potassium or of its compound with carbonic oxide. In the interior of the pipe three or four times more cyanide of potassium was condensed. The origin of the potassium is easily accounted for, as potash was found both in the iron-ore and coal, though not in the limestone.

Although cyanide of ammonium is stated to be easily generated by the contact of ammonia with carbon at a high temperature, yet Bunsen and Playfair consider that cyanogen cannot be the result of this action in the furnace; for the only source of ammonia being the coal (except, of course, the minute proportion in the air blown in), and cyanogen being only formed at the lower and hottest part of the furnace, "it would be absurd to suppose that the coal which reaches this part could contain a trace of ammonia, exposed as it has been for eighty hours to a red heat, and in one part to a temperature sufficient to reduce potash." They arrived at the conclusion, "that the nitrogen of the air introduced by the blast combines directly with carbon to form cyanogen."

Bunsen and Playfair appear conclusively to have established by experiments, that cyanide of potassium was copiously produced when nitrogen, free from all traces of ammonia, was passed over sugar charcoal in admixture with chemically pure carbonate of potash.[1]

[1] The apparatus used in these experiments consisted of a gasometer, from which a uniform stream of air was made to pass through a bottle filled with sulphuric acid, and then through a gun-barrel filled with copper-turnings. The gun-barrel was kept in a furnace, so that the air traversing it was thoroughly deprived of oxygen and passed into the gun-barrel filled with a mixture of 2 parts of charcoal from sugar, and 1 part of chemically-pure carbonate of potash, and heated

"Hence," they write, "we cannot for a moment demur to the conclusion,—That a considerable quantity of cyanide of potassium is formed in iron furnaces immediately above the point where the blast comes in contact with the glowing fuel, and that it owes its formation to a direct union of carbon with potassium and nitrogen of the air."

Cyanide of potassium is regarded by Bunsen and Playfair as an important agent in the reduction of the iron. They satisfied themselves by experiment that it is volatile at high temperatures, and suppose that it is carried upwards partly in vapour and partly in a solid state by the ascending current of gas to the so-called zone of reduction. It there exerts its well-known reducing power and is resolved into nitrogen, carbonic acid, and carbonate of potash, and this salt, not being volatile, descends along with the solid materials of the furnace to that point, where, under the influence of carbon and nitrogen, it is again converted into cyanide of potassium. Hence, they infer that in this way a large quantity of ore may be reduced in the lower part of the furnace by a comparatively small quantity of the regenerated cyanide. "The importance," they observe, "of this view of the part played by cyanide of potassium, although previously entirely neglected, will be seen when we consider that this powerful reducing agent must accumulate in the furnace to a considerable extent. The region of the furnace where the highest temperature prevails forms a limited space, beyond which the cyanide of potassium cannot extend to the lower parts of the furnace until its quantity is so much increased by the potash descending in the materials supplied that the excess of cyanide of potassium escapes volatilization and reaches the blast, where it is burnt and converted into nitrogen, carbonic acid, and carbonate of potash, the basis of which unites with the slag. We have already shown that the relation of the nitrogen to the oxygen in the gaseous mixture, collected only two and a half feet over the twyer, is 79·2 : 22·8, after deducting a quantity of oxygen corresponding to the hydrogen. If the gas generated at this place

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sufficiently to reduce potassium. In the same furnace was placed another gun-barrel filled with the same mixture, and over which a stream of dry carbonic acid was passed. When both the systems were completely filled, one with nitrogen, the other with carbonic acid, the streams of gas were allowed to pass slowly over the mixture of carbonate of potash and charcoal, both the tubes in the same furnace being kept at a temperature sufficient to reduce potassium. The gas which escaped from the tube filled with carbonic acid had all the characters of pure carbonic oxide, and burned without depositing any sublimate. The tube over which nitrogen passed emitted a gas richly laden with a white smoke of cyanide of potassium, which sublimed in such quantity as to stop the conducting-tube. When the nitrogen was passed so slowly through the sulphuric acid that the bubbles passed only once in a second, its absorption by the potash was complete, and no gas appeared at the mouth of the gun-barrel; but as soon as the temperature was lowered, so as to be under that necessary for the reduction of potassium, the absorption of nitrogen ceased. The contents of the tube over which carbonic acid had passed were examined after cooling without the detection of the smallest trace of cyanide of potassium. The mixture treated with nitrogen, on the other hand, dissolved (with the exception of its charcoal) with a very powerful odour of hydrocyanic acid. The solution exhibited all the reactions of cyanide of potassium, and yielded 6·982 grms. of cyanide of silver, which dissolved with decomposition in fuming sulphuric acid without leaving any residue of chloride of silver after dilution with water.

contained only the nitrogen and oxygen due to the air, the proportion would be 79·2 : 20·8; and hence it follows that the gases at this point must either have obtained oxygen from a source independent of the air, or that a proportion of nitrogen has been abstracted from them. Any one who has had the opportunity of observing the temperature of the furnace at this part will at once agree with the opinion that the excess of oxygen cannot be derived from the carbonic acid or iron-ore. A simple inspection of the materials enables us to reject such an explanation as erroneous, for the fused materials flowing from the furnace do not evolve gas, although they come from a point in the immediate vicinity of that where the oxygen has been taken up. We must therefore admit that this phenomenon is connected with the formation of cyanide of potassium in the furnace. The potash, as it yields its oxygen to carbon during its conversion into cyanide of potassium, assumes for every volume of oxygen lost by it two volumes of nitrogen in the form of cyanogen, and consequently the proportion of nitrogen to oxygen is necessarily increased."

It does not seem very clear why "the cyanide of potassium cannot extend to the lower parts of the furnace until its quantity is so much increased by the potash descending in the materials supplied that the excess of cyanide of potassium escapes volatilization," etc. The volatilization of the cyanide depends solely upon temperature, and cannot, so far as I can understand, be affected by the addition of potash from above. The language of the authors relating to this point is hardly so perspicuous as it might be, and I may possibly have misinterpreted their meaning.

According to the calculation of Bunsen and Playfair 380 lbs., in round numbers, of cyanide of potassium were generated in the Alfreton furnace in the course of 24 hours, and during the same period 33,600 lbs. of ironstone were smelted. From the context I conclude that calcined ironstone is here referred to. An average sample of this ironstone contained, in round numbers, 42·2 % of metallic iron; consequently, supposing reduction to have been complete, 14,179·2 lbs. or 6·3 tons (of 2240 lbs. to the ton) of *pure* iron or about 6·5 tons of pig-iron would have been reduced, *i. e.* 590·8 lbs. of pure iron per hour, or 9·84 lbs. per minute. Now, the amount of cyanide of potassium generated per hour was 15·83 lbs., or 0·26 lb. per minute. One equivalent of cyanide of potassium (K Cy = 65·149) requires 5 equivalents of oxygen in order to convert the carbon into carbonic acid and the potassium into potash. Hence, the quantity of cyanide of potassium generated per minute, namely 0·26 lb., would correspond only to the reduction of 0·37 lb. of pure iron (from Fe^2O^3); whereas 9·84 lbs. were reduced per minute. Unless, therefore, the oxidation and regeneration of the cyanide of potassium took place with a degree of rapidity hardly admissible, it is obvious that the function of this salt as a reducing agent in the Alfreton furnace could not have been so important as Bunsen and Playfair maintain. Indeed, its service in this respect must be so inappreciable that it may well have been "previously entirely neglected."

Although the experiments of Desfosses, Fownes, and others enable us clearly to account for the occurrence of cyanide of potassium in the blast-furnace, yet they do not explain the presence of free cyanogen, which Bunsen and Playfair not only detected, but quantitatively estimated, in the gaseous current at the lower part of the furnace. Supposing it to have been derived from the cyanide of potassium formed, the question arises, how was it disengaged from that compound? Further experiments are required to obtain a satisfactory answer. Is cyanogen capable of being dissociated from potassium at a very high temperature, as Deville has recently shown to be the case with carbonic acid, which is partially resolved into carbonic oxide and oxygen? Or, was the cyanogen evolved from the fuel, which always contains nitrogen? Hydrocyanic acid and hydrosulphocyanic acid occur in the products of the distillation of coal. It should be borne in mind that after Bunsen and Playfair had announced the fact of their having detected cyanogen in the gas of the blast-furnace, Ebelmen expressly sought for it, yet in vain. But the negative evidence of this observer cannot countervail the very decided and positive statement of an opposite character.

With reference to the occurrence of carbonate of potash in the lower and hottest part of the blast-furnace, it should be here stated that Berthier published a notice of the fact in 1826.[2] He analysed the scoriaceous matter rich in alkali, which was daily deposited above the tapping hole of furnaces at Merthyr Tydvil, and which the workmen collected at intervals in order to make ley with it. Berthier describes it as composed of little scoriform, black magnetic lumps—coated with a deliquescent strongly alkaline matter, and amongst which mammillated grains of slag could be perceived. This matter consisted of 38·5% of soluble salts and 61·5% of insoluble residue, of which the composition was as follows:—

SOLUBLE SALTS.

Carbonate of potash	63
Sulphate of potash	37
Silica	trace
	100

No chlorine or phosphoric acid was detected.

INSOLUBLE RESIDUE.

Silica	34·3
Protoxide of iron	26·0
Alumina	4·0
Lime	5·2
Potash	20·5
Intermixed slag	10·0
	100·0

Berthier rightly inferred that the alkali was derived from the ironstone of the coal-measures, smelted in the Merthyr Tydvil furnaces,

[2] Ann. des Mines, 1. S. 13. p. 101. 1826.

and from the ashes of the coke; that it first enters into combination with the slag, and that as this passes in front of the twyer, it is separated by volatilization and escapes in great measure through the tapping hole. It is probable that cyanogen existed in the substance analysed by Berthier, especially in the form of cyanate of potash, and that, not suspecting its presence, he failed to detect it.

Temperature of the Blast-furnace at different depths.

Direct experiments on this subject have been made by Ebelmen.[a] At the furnace at Audincourt, which, I presume, was the same as that of which the dimensions have been previously given, he obtained the following results when it was working on cold-blast with charcoal as the fuel. Three weeks after it was blown in, 115 kil. of charcoal were consumed to 306 kil. of ore, and the pig-iron made was very grey.

Temperature at the mouth.—With a "high charge" it did not suffice to liquefy sulphur, which melts at 112° C. With a "low charge" sulphur melted and remained very liquid, which proved that the temperature of the escaping gas could not have far exceeded the melting-point of that element.

Ebelmen remarks that very often, after the charge of ore in iron-smelting furnaces working with charcoal, the escaping gas becomes opaque, owing to the condensation of the aqueous vapour contained in it; and as this does not exceed 12 °/₀ or 13 °/₀ of the total volume of the gas, it follows that with a light burthen the temperature of the gaseous current must be lowered to 50° C. or 60° C. It is further stated by the same observer, that in another blast-furnace working with charcoal he found, that three weeks after it had been blown in, when the escaping gas was extinguished, the hand might be kept in it for a very long time with only a feeble sensation of heat.

In order to ascertain the temperature below the mouth, an iron rod was used, having at the end a cavity to receive a very small crucible capable of being closed with an iron plate screwed on the rod. In this crucible wires of pieces of metal of different degrees of fusibility were placed. In some experiments a little ingot of the metal was simply fixed at the end of the rod, and so lowered in the furnace.

Temperature at $8^{m}04$ *(26 ft. 4·54 in.) below the mouth, and at* $0^{m}63$ *(2 ft. 0·80 in.) above the top of the boshes.*—Silver wire was melted, and the end of the rod when withdrawn was bright cherry-red. Copper was not melted, although the rod remained 20 minutes in the furnace.

Temperature in an opening made $0^{m}90$ *(2 ft. 11·43 in.) above and opposite the twyer.*—Both copper and gold melted. The rod after remaining in 20 minutes was nearly white hot. It was covered with small drops of pig-iron and slag, and hollowed into numerous small cavities produced probably by the molten pig-iron; but it was not distorted in form.

Temperature in the twyer.—Wrought-iron melted almost instantane-

[a] Trav. Scient. 2. p. 352.

ously. A rod of iron $0^{m}02$ (0 ft. 79 in.) in diameter and $0^{m}25$ (9·84 in.) in length was completely melted in less than half a minute. Porcelain was also melted nearly instantaneously.

At the blast-furnace of Pont l'Evêque (near Vienne, Isère) working with coke, Ebelmen made several observations upon temperature.[4] The dimensions of this furnace were as under:—Width at the mouth $1^{m}25$ (4 ft. 1·21 in.), at the top of the boshes $3^{m}00$ (9 ft. 10·11 in.), at the top of the "ouvrage" $1^{m}00$ (3 ft. 3·37 in.), between the twyers, of which there were two (water-twyers), $0^{m}75$ (2 ft. 5·55 in.). Height from the mouth to the top of the boshes $7^{m}15$ (23 ft. 5·50 in.), of the boshes $2^{m}55$ (8 ft. 4·40 in.), of the "ouvrage" $0^{m}80$ (2 ft. 7·50 in.), of the hearth $0^{m}50$ (1 ft. 7·69 in.); total height of the furnace $11^{m}00$ (36 ft. 1·07 in.). The diameter of each twyer was $0^{m}072$ (2·84 in.), and that of the nozzle of each blast pipe $0^{m}067$ (2·64 in.). The pressure of the blast varied from $0^{m}026$ (1·03 in.) and $0^{m}030$ (1·18 in.) of a column of mercury, which seems remarkably small. The temperature of the blast near the twyer did not exceed 130° C. A portion of the gas was utilized and taken off midway between the mouth and top of the boshes (*au milieu de la cuve*). The charge consisted of 253 kil. of different ores (oölitic, composed essentially of earthy hydrated sesquioxide of iron) inclusive of some forge cinders and of 150 kil. of coke, with a yield of 75 kil. or 30% of pig-iron. On the average in 12 hours 24 charges were passed, and 1800 kil. of white or mottled pig-iron were made. The furnace, however, had not yet reached its full make, having been in blast only 3 weeks previously.

Temperature at the mouth 29 days after the furnace had been blown in.—With a "heavy charge" tin melted, but lead did not, so that the temperature was between 228° C. and 330° C.[5] With a "low charge" lead and zinc melted, but antimony did not, so that the temperature of the gas was between 360° C. and 430° C.

Temperature at the top of the boshes (au ventre).—Copper melted in 20 minutes. White pig-iron became disaggregated, but did not melt.

Temperature at $0^{m}67$ (2 ft. 2·38 in.) *above the twyer.*—Copper and gold melted easily. An iron rod $0^{m}009$ (0·35 in.) in diameter, and $1^{m}00$ (3 ft. 3·37 in.) in length, melted in 15 minutes. When withdrawn it was heated to incipient whiteness and scintillated in the air, but was not distorted in form. It was coated with a steely layer. Porcelain underwent no change.

Temperature at $0^{m}29$ (11·41 in.) *above the twyer.*—An iron rod $0^{m}009$ (0·35 in.) in diameter, and $0^{m}20$ (7·87 in.) in length, completely melted in less than 1½ minute. Taken out after ¾ of a minute, it had not melted, but was heated to welding whiteness and scintillated in the air. These two experiments were repeated, and with the same results.

Temperature at the twyer.—An iron rod $0^{m}009$ (0·35 in.) in diameter and $0^{m}30$ (11·81 in.) in length melted in less than half a minute. Porcelain also melted nearly instantaneously.

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[4] Trav. Scient. 2. p. 354.

[5] I give the numbers as stated by Ebelmen.

From the preceding experiments Ebelmen concludes that in the same zones the temperature of blast-furnaces working with coke is notably higher than that of blast-furnaces working with charcoal, and that these differences of temperature are in relation to the differences in composition of the gas from the same regions of these two kinds of furnaces. But it should be borne in mind that the charcoal furnace at Audincourt was working with *cold* blast, and the coke furnace at Pont-l'Evêque with *hot* blast. However, Ebelmen offers the following explanation of the fact. The temperature of the descending solid column is due to the sensible heat of the gaseous column ascending from the twyers.[6] The volume of gas is nearly proportionate to the fuel introduced; and as it is much greater, for a given weight of ore, in coke than in charcoal furnaces, its temperature will, consequently, be higher in the former than in the latter. In charcoal furnaces, for 100 parts by weight of pig-iron, the consumption of charcoal varies from 100 to 150, which by calcination during its descent is reduced to 90 and 135 of carbon; whereas, in the two coke furnaces which Ebelmen studied, the consumption of coke ranged from 285 to 200 parts by weight for 100 of pig-iron, and after deduction of 15°/₀ for ashes, from 242 to 170 of carbon. The reason assigned by Ebelmen for this difference is that charcoal is more susceptible of combustion than coke; and hence the zone, in which carbonic acid exists, appears always to be notably more extended with coke as the fuel than with charcoal. With respect to the temperature in different zones much may reasonably be expected to depend on the nature of the charge, especially the proportion of fuel, the form of the interior of the furnace, the pressure and temperature of the blast, the amount of air blown in in a given time, and possibly upon the mode in which it is distributed, whether, for example, from one, two, or several twyers.

Tunner has made direct experiments in order to ascertain the temperature of the blast-furnace at different depths; and for this purpose he used pyrometric alloys of lead and silver, of silver and gold, and of silver and platinum.[7] The apparatus in which they were placed consisted of a very short, hollow cylinder or ring of wrought-iron, 3 in. in diameter, 5 lines broad, and 7 lines deep, having on its upper surface a series of circular cavities. This ring was fixed in the top of a short cylindrical box of strong sheet-iron, of which the bottom was convex upwards and perforated like a colander with numerous round holes to allow of the free passage of the gas. On the top was fitted a conical cover of sheet-iron with a ring at the summit by which it could be attached to a chain. For the sake of greater protection there was a second outer conical cover extending to about half the depth of the inner one, and sufficiently wide to leave a free space between the two. Round the upper part of the inner cover was a series of vertical slits to allow of the escape of the gas which might enter through the perforated bottom. The apparatus, with various alloys in the holes of the ring above mentioned, was lowered in the furnace by means of a chain

[6] Op. cit. 2, p. 368. [7] Jahrbuch, 9. p. 281. 1860.

passing over a pulley at the tunnel head, and after having been left for a sufficient time was withdrawn, the depth to which it had sunk being carefully noted. It was found, as might have been anticipated, that the temperature increased at a pretty uniform rate downwards. The temperature of the gas escaping from the mouth of the furnace up to 320° C. was determined by means of the mercurial thermometer. The furnace selected for experiment was the Wrbna furnace at Eisenerz, in Styria, of which the dimensions have been stated (see p. 437). The following are the results:—

Depth in feet.		Temperature. Centigrade.	Depth in feet.		Temperature. Centigrade.
0	......	320°	21	......	840°
7	......	340°	24	......	910°
11	......	550°	25½	......	950°
15	......	640°	29	......	1150°
17	......	680°	34	......	1450°

The last result was obtained by introducing the alloy through a hole in the fore-part of the furnace (*Lichtloch*, or light-hole). The platinum alloys were required below the depth of 25½ ft., the melting points of the least fusible of the silver and gold and silver and platinum alloys being estimated at 1100° and 1175° respectively. As platinum and iron tend readily to alloy together at high temperatures, yet below the melting point of each metal, it might have been desirable to prevent direct contact between the pyrometric alloys of platinum and the iron of the ring in which they were placed.

Direct experiments were also instituted by Tunner to ascertain the temperature of the gases escaping from the mouth of a furnace in which raw, instead of roasted, spathic ore was smelted, and it was, as might naturally have been expected, found to be much lower than in a furnace working on roasted ore.[8]

In the Wrbna furnace, in which roasted spathic ore was smelted, Tunner found that the first signs of reduction to the metallic state appeared between the depths of 22 ft. and 25 ft., at a temperature estimated between 850° C. and 900° C., about 2 hours being required for the ore to descend from the mouth of the furnace to this depth. In the St. Stefan (St. Stephen) furnace, also before mentioned, in which a mixture of equal weights of raw and roasted ore was smelted, at the depth of 31 ft., which the ore reached in 6 hours in its descent from the mouth, and at 840° C., reduction to the metallic state was less advanced than in the Wrbna furnace at between 22 ft. and 25 ft. in depth. This observation Tunner considers instructive, "as showing that reduction which has commenced is more promoted by a rapid increase of temperature than by exposure to a lower temperature during a longer period." In collecting specimens of the ore for examination, Tunner employed a similar kind of apparatus to that by which he determined the temperatures, omitting the ring and placing the ore in the box with perforated

[8] Jahrbuch, 1860, ante cit.

bottom and conical covers. Experiments were made upon the ore mixed with charcoal as well as upon the unmixed ore.

DIRECT EXPERIMENTS ON THE CHANGES WHICH THE MATERIALS OF THE BLAST-FURNACE UNDERGO IN THEIR DESCENT.

Experiments of this nature were made by Ebelmen at the Clerval furnace, the dimensions of which have been previously stated.[9] The ore, etc., was lowered into the furnace in an apparatus freely permeable to gas, and then withdrawn and immediately put into well-stoppered bottles. This apparatus consisted of a bell of strong sheet-iron in the form of a truncated cone, about 1 litre (61 cubic inches or 1·76 pint) in capacity. It had a ring at the top, by which it was attached to a very strong chain passing over an iron pulley fixed about 2 metres (6 ft. 6·7 in.) over the mouth of the furnace. It was closed at the bottom by a moveable iron disc, which, as well as the bell itself, was perforated with numerous holes to allow of the entrance and free circulation of gas. The chain was marked at intervals, so that the distance to which the bell descended in the furnace might be measured. It required at least four men to pull up the apparatus from the depth of $4^{m}85$ (15 ft. 10·95 in.). By means of this apparatus Ebelmen also ascertained the rate at which the carbonization of wood proceeds at different depths in the blast-furnace.

The iron-producing materials operated upon were two varieties of earthy brown hæmatite and rich slag produced at the end of the process of converting cast into malleable iron in the charcoal hearth. The composition of these ores and of the slag is stated by Ebelmen as follows:—

	I.	II.
Water	15·0	10·0
Carbonate of lime	..	36·8
Carbonate of magnesia	..	trace
Sesquioxide of iron	59·6	36·2
Oxide of manganese	0·4	0·4
Oxide of chromium	trace	trace
Alumina, soluble	6·0	3·0
Silica, soluble	5·6	3·8
Insoluble residue, silica	12·2	8·8
Insoluble residue, alumina	1·2	0·6
	100·0	99·6

	III.
Metallic iron	1·4
Protoxide of iron	84·1
Protoxide of manganese	0·7
Oxide of chromium	0·8
Alumina	0·2
Lime	trace
Silica, soluble	8·6
Quartzose sand	1·8
Charcoal and loss	2·4
	100·0

I. This ore was pisolitic, consisting of very round particles not exceeding a pea in size. Its powder was brownish yellow. The locality was La Chapelle, Saint Quillain (Haute-Saône).

II. It was in the form of small oölitic grains of hydrated sesquioxide of iron, disseminated through an argillo-calcareous matrix, and occurred in the lower part of the limestones of the uppermost Jurassic bed. It was broken in pieces of the size of walnuts. The residue, insoluble in acids and caustic potash, was composed of grains of hyaline quartz

[9] Trav. Scient. 2. p. 185. I shall translate Ebelmen's own language as far as I can render it available.

easily distinguishable under a lens, and mixed with a small quantity of very white and very light clay. The ore contained a little phosphoric acid, which was not estimated, and here and there some particles of iron pyrites. The locality was Laissey (Doubs).

III. It was badly melted and full of blisters. Acids easily acted upon it, with the disengagement of some hydrogen. The presence of a sensible amount of oxide of chromium in this slag is remarkable, and proves that the Clerval pig-iron must contain that metal.

The results of Ebelmen's experiments are recorded in the following tables:—

First Series with the Ore of La Chapelle.

	I.	II.	III.	IV.
Water	5·2	0·6	..	..
Metallic iron	..	..	trace	26·7
Protoxide of iron	3·2	32·5	41·8	35·0
Sesquioxide of iron	63·4	33·0	26·0	..
Oxide of manganese	0·4	0·5	0·6	0·6
Lime	..	..	..	0·4
Alumina, soluble	6·6	8·2	8·0	7 3
Oxide of chromium	..	..	..	trace
Silica, soluble	6·0	7·0	7·8	21·6
Clay { silica	13·2	16·8	14·8	4·6
Clay { alumina	2·0	1·4	1·0	3·0
	100·0	100·0	100·0	99·2

Second Series with the Ore of Laissey.

	I. a.	II. a.	III. a.	IV. a.
Water	3·8	..	..	..
Carbonate of lime	41·0	40·6	26·6	..
Caustic lime	..	..	4·0	37·4
Metallic iron	..	..	..	10·0
Sesquioxide of iron	37·0	27·8	24·1	..
Protoxide of iron	trace	12·7	17·5	30·2
Oxide of manganese	0·4	0·4	0·4	0·4
Oxide of chromium	trace	..	..	trace
Alumina, soluble	3 2	3·1	4·0	3·0
Silica, soluble }	14·6	15·4 {	4·7	6·4
Quartz }			17·3[1]	12·2
	100·0	100·0	98·6	99·6

Observations on the preceding analyses.—Exps. I. and I. *a.* The products analysed had been exposed in the bell at the same time. The ore of La Chapelle was in grains, and that of Laissey in tolerably large pieces: fragments of common charcoal were also put in with the ore. The bell was dropped into the furnace between the charcoal and the ore, and taken out 2 hours afterwards from the depth of 2^{m} 50 (8 ft. 2·43 in.): it was not red-hot. The furnace had been twice charged in the interval. The powder of the La Chapelle ore was dark red, slightly inclining to black. A notable quantity of it was attracted by the magnet. In the calcareous ore of Laissey reduction did not seem

[1] Clay and sand.

to have begun: its powder was bright red, without any shade of brown, and hardly were a few particles taken up by the magnet.

Exps. II. and II. *a*. Both ores were exposed simultaneously in the bell, which remained in the furnace 4^h 25^m, and was taken out from a depth of 4^m 35 (14 ft. 3·26 in.): at the moment of its removal from the furnace it appeared to be dull red-hot. The furnace had been charged 6 times in the interval. The powder of the La Chapelle ore had become pure black, and wholly attractable by the magnet. The particles of the ore had not changed in form, but were more fragile than previously. The powder of the Laissey ore had also become black, and all the iron existed in the state of magnetic oxide.

Exps. III. and III. *a*. Precisely the same course was followed as in the foregoing experiments. The bell remained 5½ hours in the furnace, and was taken out from a depth of 5 metres (16 ft. 4·85 in.), or only 0^m 7 (2 ft. 3·56 in.) above the top of the boshes (*au-dessus du grand ventre*): it was cherry-red when it left the furnace. The suspending chain was red-hot to about 4 metres (13 ft. 1·48 in.) from the mouth. The ore of La Chapelle had not changed in form: its powder was black, inclining to grey, and strongly magnetic. The powder of the Laissey ore was dark grey, and still effervesced pretty strongly with acids.

Exps. IV. and IV. *a*. Finery cinder was put into the bell along with the ores and charcoal. There were also tolerably large fragments of bricks made from a mixture of pulverized finery slag with about 12°/$_0$ of charcoal powder, and 25°/$_0$ of slaked lime mixed with water to the consistency of paste: with a mixture of this kind well-kneaded bricks (*briquettes*) were made, which, on sun-drying, were hard enough to resist the pressure of the finger. The bell, charged with these various matters, was dropped into the furnace between the charcoal and the ore, and remained in the furnace 6^h 25^m, the furnace meanwhile having received 11 charges, or 1 every 35 minutes. On the day of the experiment the furnace worked more rapidly than usual. The bell was taken out from a depth of 5^m 70 (18 ft. 8·41 in.), and was still red-hot when it left the furnace: it was sensibly distorted, the temperature to which it had been exposed having been sufficient to soften wrought-iron. The ore of La Chapelle had undergone incipient fusion. Its component particles were soldered together, without having altogether lost their shape. Their surface was shining, and indicated the commencement of scorification. They were easily pulverizable. The powder was iron-grey in colour: it contained a considerable quantity of metallic iron, which flattened out and acquired metallic lustre under the pestle. By the action of acids it yielded much hydrogen, having the same odour as that evolved from iron-filings; and thus proving, as Ebelmen remarks, that the reduced iron had already taken up carbon. In the analysis it will be noticed that a very large proportion of the silica, originally present in the ore in the free state, had now entered into combination. The Laissey ore had kept its form: its powder had become bright grey. This analysis demands particular notice. Ebelmen satisfied himself that the ore did not contain any sesquioxide of iron, and hence

arises a difficulty which he pointed out. His words are as follow:—"Berthier has demonstrated that in cementing sesquioxide of iron in charcoal, the scale-oxide (*oxide des battitures*) passes immediately to the state of metallic iron; and, on the other hand, that on dissolving in acids the mixture of metallic iron and scale-oxide, the solution contained a certain amount of red oxide. There is consequently every reason to believe that in this case a combination was effected between the protoxide of iron and the silica, notwithstanding the feeble proportion of gelatinous silica, and the large amount of caustic lime in the ore." Now, assuming the correctness of Berthier's statement and of Ebelmen's analysis, the difficulty does not seem to be satisfactorily removed by the explanation just presented. How 30·2 % of protoxide could have existed as silicate in the presence of 37·4 % of lime, with only 6·4 % of silica, it is not easy to understand.

The finery slag and the mixture of this slag, subjected to experiment, had the following composition:—

	Slag *per se.*	Mixture of slag.
Metallic iron	4·7	28·9
Protóxide of iron	82·2	32·0
Oxide of manganese	0·7	0·5
Oxide of chromium	0·8	0·4
Lime	..	16·8
Alumina	0·4	1·2
Silica, soluble	10·2	13·2
Silica, as sand	1·0	..
Insoluble residue	..	5·4
Charcoal	..	1·2
Sulphur	..	0·1
	100·0	99·7

The fragments of the slag had undergone no change either in form or in the character of their fracture. Their surface only had become pale grey, and when rubbed acquired metallic lustre. The fragments of the slag in brick had only become rounded by friction: its powder was very pale grey. According to Ebelmen, the greater part of the charcoal originally in admixture had been volatilized, either by the reduction of the protoxide of iron, or by the decomposition of the water of the hydrate of lime. The value of the lime in displacing the protoxide of iron from its combination with silicate, and in promoting reduction, is clearly shown by result of the analysis. Ebelmen calls attention to the fact that Berthier had long previously suggested that slags, consisting essentially of silicate of protoxide of iron, might probably be smelted with advantage by mixing them, in the state of powder, with lime and waste charcoal-dust, and making the mixture into bricks in the manner described.[2] The larger proportion of silica, both in the soluble and insoluble states, in the brick-slag than in the original slag, Ebelmen attributes to the earthy matters in the common charcoal-dust which he used in the experiment.

Ebelmen has drawn up from his results the following tabular state-

[2] Tr. des Essais, 2. p. 305.

ment, in order clearly to indicate the degree and rapidity of reduction of the two kinds of ore operated on at the four different depths of the furnace, as recorded in the experiments above described:—

		2m 5	4m 35	5m 00	5m 70
	Depth below the mouth	2m 5	4m 35	5m 00	5m 70
	Numbers of charges	3	6	8	11
Ore of La Chapelle.	100 parts are reduced to	89·30	82·31	81·22	72·91
	100 parts have lost — water	10·40	14·40	15 00	15·00
	100 parts have lost — oxygen	0·30	3·30	3·78	12·09
	100 parts of sesquioxide of iron have lost of oxygen	0·48	5·55	6 33	20·16
	Average rapidity of reduction	0·16	1·69	0·39	4·61
Ore of Laissey.	100 parts are reduced to	93·60	88·79	84·74	68·12
	100 parts have lost — water	6·40	10·00	10·00	10·00
	100 parts have lost — oxygen	0·00	1·21	1·66	5·88
	100 parts have lost — carbonic acid	0·00	0·00	3·60	16·00
	100 parts of sesquioxide of iron have lost of oxygen	0·00	3·34	4·58	16·24
	Average rapidity of reduction	0·00	1·12	0·62	3·89

The rapidity of reduction (*vitesse de réduction*) has been deduced in each experiment by dividing the amount of oxygen yielded by 100 parts of sesquioxide of iron, in the interval comprised between two consecutive experiments, by the number of charges which separate them. Thus, in order to have the average rapidity of reduction of the ore of La Chapelle in that part of the furnace which is comprised between the 3rd and 6th charges, it suffices to reduce the fraction $\frac{5\cdot55 - 0\cdot48}{3} = 1\cdot69$. Ebelmen preferred to deduce the rapidity of reduction from the number of charges rather than from the time the ore remained in the furnace, and the reason assigned for this preference is as follows:—The charge being constant in volume, the ore will always be at the same height in the furnace, in two consecutive experiments, when covered by the same number of charges; whereas, on the contrary, in equal times, the ore does not always descend at the same rate in the furnace on account of the varying velocity of the blast. The Clerval furnace contained 25 charges, *i. e.* the ore only reached the twyer after having been covered by 25 successive charges.

It will be observed that reduction decreased considerably in rapidity between the 6th and 8th charges, while it proceeded with great energy between the 8th and 11th charges. In the first instance, according to Ebelmen, magnetic oxide of iron was converted into scale-oxide; and in the second instance scale-oxide was reduced to the metallic state. At the same height in the furnace, the reduction, in the case of the calcareous ore of Laissey, was less advanced than in that of the ore of La Chapelle; and this Ebelmen supposes was due to the fact that the former was in comparatively much larger fragments, and consequently

presented less surface, with the same bulk, to the agents of reduction than the latter. While reduction is slowly effected in the upper part of the furnace, it takes place with great energy, in a very limited zone, a little above the top of the boshes in the Clerval furnace. The cause which Ebelmen assigns for this sudden variation in the rapidity of reduction is the disengagement of carbonic acid from the limestone used as flux, and from the calcareous ore. In the 3rd experiment the calcareous ore of Laissey had lost only a small quantity of its carbonic acid, while in the 4th experiment it had lost the whole of it, and the lime was completely caustic. The evolution of carbonic acid, then, coincides in a striking manner with sudden decrease in the rapidity of reduction. But carbonic acid, in passing from the solid state, as it exists in carbonate of lime, to the state of gas, absorbs a very large amount of heat, and must necessarily lower the temperature of that part of the furnace in which such absorption takes place. The ascending current of gas from beneath, in traversing the zone of the furnace, in which the calcination of the carbonate of lime occurs, must lose a portion of its sensible heat, and, becoming mixed with the carbonic acid expelled from its combination with lime, must proportionately lose in reductive power.

UTILIZATION OF THE GASES ESCAPING FROM BLAST-FURNACES, OR, AS IT IS NOW TERMED, THE WASTE GAS.

Evidence will be adduced of the fact, that more than half a century has elapsed since the important practical problem of the utilization of the waste gas of iron-smelting furnaces was solved in a satisfactory manner in France; and yet it is only about twenty-five years ago that it began to attract the serious attention of ironmasters, not in Great Britain, but on the continent of Europe. In this country Mr. James Palmer Budd was, if I mistake not, the first ironmaster who successfully applied the gas; and the mode in which he did this will be presently described in detail. It was exceedingly crude, in as much as Mr. Budd availed himself chiefly of the sensible heat of the gas, and allowed much of the carbonic oxide to escape unburned into the air, thus losing the enormous amount of heat capable of being developed by the combustion of that gas! The complete utilization of the waste gas is now effected with great pecuniary advantage in South Wales and Scotland, and in a few localities only in England. Some ironmasters in South Staffordshire and elsewhere maintain that this modern improvement is unsuitable to their furnaces, and urge in proof that not a few of their brethren have incurred considerable expense in attempts to apply it, and have signally failed. They should, however, remember that practical difficulties generally attend innovations of any kind, especially in metallurgical processes, the direction of which has been too often entrusted to so-called practical men, who have no knowledge beyond that of rule of thumb; who are not unfrequently as conceited as they are ignorant, and who systematically oppose every change which does not originate with themselves. Happily, there are now

really enlightened and well-educated practical men; but many of the old stamp are still to be met with, particularly in the midland districts. Accumulated wealth, abundant supplies of ore and fuel, and a long established name in the market have in many cases produced indifference to progress, and engendered an obstinate spirit of conservatism on the part of our ironmasters; but circumstances are not so smooth and agreeable as they once were; and it is evident that the men who have hitherto despised improvement must now bestir themselves in order to hold their ground against adventurous, skilful, and persevering rivals. Competition was, probably, never so fierce or so formidable as at present, and economy in the cost of production has become a prime necessity. The time will assuredly arrive when the valuable gaseous fuel still so wastefully allowed to escape from many of our blast-furnaces will be everywhere utilized.

In June, 1814, Berthier published an interesting and important paper on the successful application in France of the waste gas to various purposes, such as the conversion of iron into steel by cementation, and the burning of lime and bricks.[3] The credit of this application is due to M. Aubertot, who was a proprietor of iron-works in the department of Cher. He obtained a patent for it in France in 1811, and contented himself with only reserving for his own exclusive use that part of it which was connected with the manufacture of steel by cementation. This fact deserves to be specially recorded as a singular instance of unselfish generosity on the part of a patentee. Berthier states that "so far from thinking of preventing ironmasters from availing themselves of all the rest, with generous complacency he is anxious to give them the most detailed information and every instruction which they desire. Nearly all his neighbours have employed his processes during several years, and some gain largely by them."[4] Berthier visited four works either belonging to, or managed by, M. Aubertot, so that his description was founded on personal observation; and it is only just to his memory to state that he seems clearly to have foreseen the value of the application in question.[5]

For burning lime or bricks the kiln, which was prismatic in form, was erected on the platform at the top of the furnace, and close to the mouth on one side. The flame entered the kiln immediately above the mouth, through an opening 0^{m} 5 (1 ft. 7·69 in.) square; and on each side there was a little wall in order to protect it from the wind. On the fourth or free side charging was effected. At the entrance into the kiln was a cast-iron plate or door, which could be moved up and down and acted as a damper. The kiln was charged through a lateral opening. At the top was a central chimney, and at each angle there was simply a hole communicating with the interior; by this means the gas within was uniformly diffused, and equality of temperature secured.

[3] Sur plusieurs moyens imaginés pour employer la flamme perdue des hauts fourneaux, des foyers de forges, etc. Journ. des Mines, 35. p. 375. June, 1814.

[4] Op. cit. p. 377.

[5] He thus expresses himself on the point:—"J'ai pensé qu'il serait très-utile de porter à la connaissance de tous les métallurgistes une invention qui peut être aussi féconde." P. 377.

It was, of course, necessary to charge the kiln in every case, so that the gas might circulate freely upwards through the mass. After charging the kiln the cast-iron door was at first only raised 0m 05 (1·97 in.) or 0m 06 (2·36 in.), when a portion of the flame penetrated rapidly, and soon took a regular course. This "little fire," as it was termed, was kept up from 24 to 36 hours, after which the cast-iron door was gradually raised until the opening was from 0m 16 (6·30 in.) to 0m 20 (7·87 in.) high. The whole column of flame from the mouth of the furnace now entered the kiln, producing what was termed the "great fire," which was maintained during 3 or 4 days. The kiln soon acquired its *maximum* temperature, which was that of white redness. On raising the door higher, it was found that the temperature quickly decreased, owing to the entrance of a rapid current of cold air. The working of the furnace was not in the least interfered with by the operations of the kiln men. For the production of steel by cementation, a converting chest capable of holding from about 15 to 18 cwts., similar to what will hereafter be described, was constructed in the same position as the lime or brick-kiln.

The calorific effect of the waste gas was rightly attributed by Berthier, partly to its sensible heat, and partly to the heat developed by its combustion in contact with atmospheric air. In proof of the high temperature produced by such combustion, he refers to an experiment of M. Curandau, which consisted in directing the current of gas from the mouth of a blast-furnace, horizontally into the arch of a reverberatory furnace. The language which Curandau has employed in describing this experiment, and which is cited by Berthier, deserves a literal translation. It is as follows: "When the arch was penetrated with the same heat as the gas which I caused to flow into it, concurrently with a stream of external air, this heat favoured their ignition, from which there resulted an emission of caloric of an intensity truly surprising; which proved to us, and to me in particular, that this phenomenon was the result of a combustion, and not that of the heat concentrated by the current of the gases which flowed under the arch."[6]

The utilization of the waste heat of blast-furnaces for similar purposes, and on substantially the same principle as Aubertot's method, was patented in England in 1832 by a Mr. Moses Teague,[7] as the following extracts from his specification will demonstrate:—"This improvement consists in making use of or employing the flame and heat (heretofore discharged into the open air) from the tops or tunnel heads of blast-furnaces or cupilos (*sic*) used for the making and smelting of pig-iron, by means whereof the said flame and heat is made to act upon the ores, mines, and minerals about to be smelted, previous to the same being deposited into the interior of the furnace or cupilo. . . . The method of applying the same is by diverting the flame and heat (usually passing out of blast-furnaces or cupilos into the open air), and

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[6] Op. cit. p. 395.

[7] An Improvement in the Making and Smelting Pig-Iron. A.D. 1832. No. 6211.

causing the same to pass in, upon, or through one or more ovens, stoves, buildings, or erections to be fixed on, in, or upon, or near to, or adjoining the tops or tunnel heads of the said furnaces or cupilos. . . . The said flame and heat is diverted from its usual course, and driven or discharged into or through the said ovens, &c., by partially contracting or stopping up altogether the tops or tunnel heads of the said blast-furnaces or cupilos, either permanently with brick, masons' work, or any other mode; or by one or more moveable dampers, doors, or valves, to be fixed on, in, or upon them, or the said ovens, &c. By this means the flame and heat is diverted and caused to pass into or through the ovens or stoves, which have one or more chimneys or flues attached thereto, in order to carry off the superfluous heat, flame, and sulphur." Illustrative drawings accompany the specification.

A few years ago I was informed by Mr. Philip Taylor, head of the well-known mechanical engineering firm at Marseilles, that in 1840 he was engaged in constructing and erecting the blast-engine for iron furnaces at Rustrel, in the department of Vaucluse, in France. As in this locality the supply of wood for charcoal-burning was not abundant, and as the carriage of coal or coke was very expensive, it was important to economize fuel; and, accordingly, Mr. Taylor proposed to heat the boilers of the blast-engine either wholly or partially by the waste gases of the furnaces. "Many attempts," he writes, "had been made to employ this flame [from the mouth of the blast-furnace] to produce steam; but the mode adopted had been by placing the boiler on the top of the furnace, so that the ignited gas acted direct on the boiler. The effect disappointed those who tried this plan, for without doubt a large portion of the gas was not ignited for want of a due admixture of atmospheric air. Another objection to this plan arose from the distance which the steam had to be conveyed to the engine and the water to be raised to feed the boiler. The plan which I adopted was to close the top of the furnace and thus prevent the ignition of the gas, which made its escape through a large cast-iron pipe which passed from the upper part of the furnace to the boilers, which were placed at some distance from the base of the furnace. A mode of charging the furnace had to be contrived without opening the furnace top, and this was accomplished. My opinion was that this scheme could only succeed by insuring a due admixture of atmospheric air with the gas, so that complete combustion might be produced. To effect this admixture, the gas from the main-pipe was made to pass under the front end of the boiler through a number of narrow passages or slits, and the atmospheric air was admitted by other similar passages intervening with the gas-passages. To admit more or less air a valve was placed on the main air passage. The entire success of this project was soon found to depend on the use of this valve; for, if too much air entered, enough steam was not generated to work the engine, and, if too little, the same result followed. But when we hit the right proportion steam blew off at the safety-valve most abundantly. Care must be taken if a boiler is heated by gas, as above described; as in case the furnace ceases to have the blast on, an explosion would be likely to take place,

if, on putting on the blast, the gas and air are admitted to the boiler without some fire is placed under the boiler to ignite it on arriving."

Mr. Taylor further informs me, that more than sixty years ago he well remembers an attempt having been made at the foundry of Gurney and Aggs, at Norwich, to raise steam by placing the boiler on the top of the cupola; but it was not successful, and the water did not boil.

In 1845, Mr. James Palmer Budd obtained a patent for the application of the "heat, flames, and gases of the blast-furnace" to the heating of hot blast stoves.[g] This application was carried into practice in the Swansea Valley, at the Ystalyfera furnaces working with anthracite as the fuel. The hot-blast stove consisted of a chamber containing two horizontal cast-iron mains at the bottom, one for the admission of the cold-blast, and the other for the exit of the hot-blast, the two mains being connected by cross-pipes supporting numerous vertical syphon pipes of cast-iron. The stove was built at the side of the upper part of the furnace, one such stove being thus constructed in the brickwork between two adjacent furnaces. Each stove was connected with a stack about 25 ft. higher than the mouth of the furnace. The gas was conveyed into the stoves by 3 or 4 horizontal flues, of about 12 in. in diameter, proceeding from opposite sides of each furnace at about 3 ft. below the mouth. Mr. Budd has published a paper on this subject, illustrated by a wood-engraving, in which 4 flues are shown on one side of a furnace, and 3 on the opposite side.[h] By means of a damper on the top of the stack the supply of gas to the stove could be exactly regulated. Mr. Budd estimated that the quantity required to heat the blast for a single furnace, did not exceed $\frac{1}{4}$ of the total quantity escaping from the tunnel-head of a single furnace. The following statement should be specially noted. "I attempt," writes Mr. Budd, "no combustion of the gases, for as they rise from the furnace and enter the stove with a temperature of about 1800° F. (982° C.), and leave it at a temperature of about 800° F. (427° C.), whilst all the heat I require for the blast is 600° F. (314° C.), the mere passage of them, as heated vapours through the stove, gives me all the temperature I want; whilst, having no combustion going on, the pipes remain uninjured, the bricks unmelted, and the apparatus always effective. My reason for thinking there is little combustion of the gases at 3 ft. below the surface of the materials is, that when the vapours pass through the stove and reach the top of the stack, where they come in contact with the atmosphere, there bursts out a bluish flame, visible at night, which is speedily extinguished from a reduction of temperature below the point at which the mixed gases burn. When, on the contrary, I allow the materials in the furnace to fall below the mouths of the flues, a combustion of the gases takes place previous to entering the stove, and the vaporous appearance disappears."

In 1848, when I visited Mr. Budd's works at Ystalyfera, he had suc-

[g] A.D. 1845, Jan. 16. No. 10,475.

[h] Report on the advantageous use made of the Gaseous Escape from the Blast Furnaces at the Ystalyfera Iron-Works.

[i] From the Report of the British Association for the Advancement of Science for 1848.

cessfully applied the waste gas to the raising of steam. The nearest boiler was 46 ft. from the furnace; and although the gas was conducted all this distance to the boiler, yet it is reported that it raised twice as much steam as when fired with coal. The boiler tube was divided by a brick partition into two compartments, and the gas passed 4 times through and under the boiler, a total length of 120 ft. The boiler stack, which was 80 ft. high and 6 ft. in diameter, produced "an over-powering draught." Mr. Budd calculated the saving on this boiler at 35 tons of anthracite per week, and the annual saving in money at 350*l.*

So satisfied was Mr. Budd with the success of his utilization of the waste gas, that he even ventured to draw the following conclusion:— "It would appear to be more profitable to employ a blast-furnace, if as a gas generator only, even if you smelted nothing in it, and carried off its heated vapours by flues to your boilers and stoves, than to employ a separate fire to each boiler and each stove. These considerations irresistibly suggest to me a great revolution in metallurgical practice; a new arrangement in fact of furnaces and works, by which considerably above 1,000,000*l.* a year might be saved in the iron trade alone."

Mr. Budd's paper contains some extraordinary statements by Schafhäutl concerning the composition of the gas which escaped from the mouth of the Ystalyfera furnaces, and these should not be passed over in silence. The two following analyses by the Munich philosopher are given:—

	I.	II.
Carbonic acid	00·136	9·546
Carbonic oxide	18·974	12·012
Hydrogen	27·844	21·278
Marsh-gas	3·212	2·548
Sulphurous acid, with traces of arseniuretted and phosphuretted hydrogen	trace	0·111
Nitrogen	49·844	54·505
	100·010	100·000

I. The gas was taken off 16 ft. below the surface of the coal and ore. II. The gas was taken off only 1 ft. below the surface of the coal and ore.

The fuel, it will be remembered, was anthracite, and yet the waste gas contained upwards of 20 % of hydrogen! Well may Mr. Budd write, "the large quantity of hydrogen in the analysis is puzzling, as anthracite coal contains only 2 % or 3 %." It is not only puzzling, but absolutely inexplicable, and is moreover in direct opposition to the results of every other observer having the least claim to a scientific position. If Schafhäutl were able to estimate quantitatively 0·111 per cent. of sulphurous acid, with traces of arseniuretted and phosphuretted hydrogen, it is difficult to understand how he should have committed any serious error in the determination of the hydrogen; and yet it is impossible to avoid the conclusion that he has, if we believe Bunsen, Ebelmen, and others.

The modes of taking off the waste gas are essentially of two kinds, namely, those in which the mouth of the furnace remains permanently

open, and those in which it is permanently closed, except during the time of charging. In the first case the gas is only partially collected and economized. I do not propose to describe in detail all the contrivances which have been resorted to in carrying out either of these systems, because, in many instances, the modifications are so slight as not to render such an extended description either necessary or desirable.

Modes of taking off the Gases with open-mouthed Furnaces.

By lateral openings near the top of the furnace.—One of the simplest methods is shown in the engraving of the Swedish blast-furnace (p. 376, 377), in which the gas is withdrawn through two quadrangular, similar, and opposite openings, *m*. In the Ystalyfera anthracite furnaces of Mr. Budd, which have been previously alluded to, the gas was taken off through several circular openings at a short distance below the level of the solid contents of the furnace, their exhaustion being effected by means of a high stack. In some furnaces there is an annular passage or flue near the mouth, extending all round, and communicating with the interior by several short passages; and in this case also the aid of a stack is required for exhaustion. The short passages should obviously incline downwards, in order to prevent the materials of the charge from lodging in them. The particular arrangement just described has been in use at Dundyvan, in Scotland, and at Pontypool, in South Wales.[1] At Wasseralfingen, in Wurtemberg, so long ago as December, 1832, the gas from a furnace working with charcoal as the fuel was taken off immediately below the mouth on one side, whence it passed upwards through an inclined

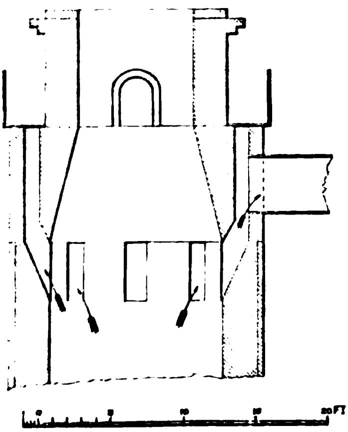

Fig. 79. Dundyvan method.

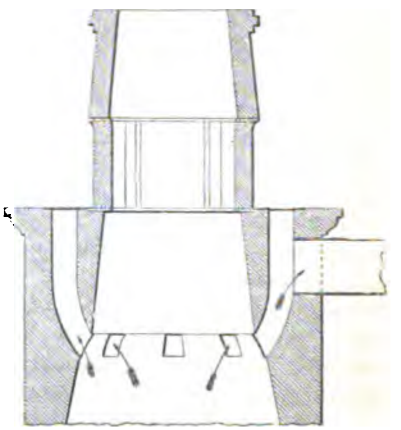

Fig. 80. Pontypool method.

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[1] On the Arrangement of the Materials in the Blast-Furnace, and the Application of the Waste Gases. By S. H. Blackwell, of Dudley. Proceedings of the Institution of Mechanical Engineers. Birmingham, Oct. 27, 1852, p. 191 et seq.

passage lined with cast-iron and entered a hot-blast stove erected on the platform close to the tunnel-head.[2]

In 1842, Pfort published the following account of an arrangement at a furnace working with charcoal as the fuel at Veckerhagen.[3] It is represented in the accompanying wood engravings. Fig. 81 is a vertical section of the mouth and throat of the furnace, through the centre, and fig. 81*b* a horizontal section. Two cylinders of cast-iron, *a* and *b*, each 5 ft. high and 1 in. thick, but of which one is 1 ft. wider than the other, form the mouth.[4] The inner cylinder, *b*, is a prolongation upwards of the shaft of the furnace, and between the outside of it and the inside of the outer cylinder is an annular space 6 in. broad, from which the gas passes through the passages, *c*, *d*, *e*, provided with dampers, so that it may be sent through any one or more at will. From *c* the gas was used to heat the blast, from *d* to raise steam for an engine of 6-horse power, and from *e* to carbonize wood in kilns. At Ebbw Vale the gas has been taken off in a similar manner, except that only a single cylinder 7 ft. 9 in. in diameter and 7 ft. 9 in. high was inserted in the mouth, the gas being withdrawn from the space between the outside of it and the adjacent lining of the furnace.[5]

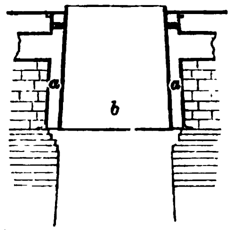

Fig 81.

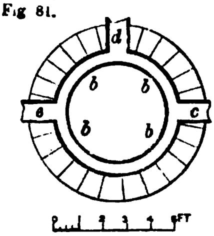

Fig. 81*b*. Veckerhagen method.

At the Iron-works of Messrs. Schneider and Hannay, at Barrow-in-Furness, the gas is taken off through a vertical brick tube, the bottom of which descends 6 ft. below the mouth of the furnace, where it rests on six narrow arches or arms of brickwork, proceeding from the lining of the furnace at equal distances apart and converging towards the centre. The materials are charged through the openings between these arches. The tube is about $\frac{1}{4}$ of the diameter of the mouth of the furnace; it is provided with a horizontal sliding damper, and at the top is connected with a large horizontal gas-main, passing through the tunnel-head and over several furnaces in succession. In addition to a high stack, fans[6] are employed to aid in causing exhaustion. Owing to the great length of the gas-main and its liability to variation in temperature in different parts, expansion joints are employed, each of which consists of a pair

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[2] Notice sur l'appareil qui sert à chauffer le vent alimentant les hauts-fourneaux de la fonderie royale de Wasseralfingen. Par M. Voltz. Ann. des Mines, 3 S. 4. p. 77. 1833.

[3] Der Flammenofenbetrieb mit brennbaren Gasen zu Veckerhagen. Von Hütteninspector C. Pfort, Studien des Göttingischen Vereins Bergmännischer Freunde, 5. p. 1. 1842.

[4] I have not reduced these measures to English, as the difference between the two is in this case unimportant.

[5] S. H. Blackwell, op. cit.

[6] The employment of the fan (ventilator) for promoting the removal of the gas occurs in De Meckenheim's Specification of a Patent for "Improvements in the Manufacture of Iron." A.D. 1842. No. 9373. The apparatus claimed in this specification for taking off the gas and utilizing it may be ingenious, but owing to its complication, it is certainly not practicable.

of large concave discs of iron placed vertically, joined at their circumference, and having their concave surfaces directed towards each other, just as in the case of the common aneroid barometer. A model of these Works was in the International Exhibition of 1862.

In the specification of a patent granted to Mr. William Oakes in 1857, the removal of the gas through a central shaft or flue at "the top of the blast-furnace" is claimed.[7] An illustrative drawing is given, in which the bottom of this central flue does not, as in Schneider and Hannay's furnaces, descend below the mouth, but is on a level with it. The vertical exit tubes communicated at the top with a horizontal gas-main. The application of horizontal trap-doors or valves for closing the mouth is also claimed in the above specification. At Pontypool in 1859 vertical pipes, connected with a horizontal main above, were used to take off the gas. They were, however, not in the axis of the furnace, but on the exterior on one side near the mouth, which was fitted with the cup and cone arrangement.

Modes of taking off the Gases with close mouthed Furnaces.

Hopper with double slides.—In the Zollverein department of the first International Exhibition in London, in 1851, there was a drawing of this arrangement fitted to a furnace, working with charcoal as the fuel. Over the mouth of the furnace was fixed a rectangular iron box widening pyramidally outwards at the top like the hopper of a flour-mill. At the bottom of this box was a sliding horizontal damper, and another similar one above near the small base of the pyramidal portion. In charging, the lower damper was closed, and the upper one, of course, opened; after which the upper one was closed and the lower one opened, when the charge dropped into the furnace. By this means the interior of the furnace was never in direct communication with the atmosphere.

Cup and Cone.—This plan is extensively used in blast-furnaces in South Wales. It is represented in the engraving of the Ebbw Vale furnace at p. 367, which scarcely needs any descriptive notice. A short, inverted, hollow, truncated cone of cast-iron, *e*, is fixed in the mouth of the furnace, and in the axis is a hollow cone of cast-iron, *f*, suspended by an iron chain attached to one end of a lever, having a counterpoise at the other end. This lever may be moved up and down by suitable apparatus. When the cone is in the position shown in the engraving the mouth of the furnace is closed. The charge of ore, flux, and fuel is thrown into the mouth-piece while thus closed, and, on lowering the cone, *f*, it immediately falls into the furnace, being distributed necessarily round the circumference. The gas is taken off through the pipe, *g*, and conveyed where required. Should the suspensory chain break, which sometimes happens, the cone, *f*, is lost, and must be allowed to sink along with the materials in the furnace. In order to provide against this contingency at the Pontypool Iron-works, where the cup and cone plan was in use, a loose chain

[7] Improvements in the Manufacture of Iron. A.D. 1857. No. 493.

passed over the lever, by which the cone was moved up and down, and was attached at each end to the cone, so that if the latter became detached it would be immediately caught by this chain. The charging is very quickly effected, and only a trifling proportion of gas escapes into the air.

My friend, Mr. George Parry, of the Ebbw Vale Iron-works, was the first to apply the cup and cone, March, 1850; and he derived the idea of this application from the published description of an apparatus constructed by the late Mr. Jessop, of the Butterley and Codnor Park Iron-works, Derbyshire, for charging blast-furnaces, so that the materials might be equally distributed round the inside.[8] The description is illustrated by a small woodcut,[9] and is as follows:—It consists of "an iron cylinder, open at top and bottom, 4 ft. in diameter and 2½ ft. in height, in the inside of which a hollow cone of iron is suspended, with its apex uppermost, so that while the base of the cone is kept above the level of the bottom of the cylinder it shuts it; but on the cone being lowered below that level, it allows the charge of materials resting all round the slant surface of the cone to fall down equally round the side of the cylinder into the furnace."

At the Blaina and Cwm Celyn Iron-works, the plan has been tried of suspending the cone with its base *above* the opening in the inverted conical mouthpiece, so that if the suspensory chain should break, the cone would not drop into the furnace, and the damage might be quickly repaired. In this case the materials charged would fall towards the centre, and not towards the circumference as in the other method; but this effect might be in a great degree counteracted by decreasing the depth of the mouth-piece, and giving it a steep inclination, as was actually done. I saw the furnace with this arrangement of the cup and cone in operation in 1859.

Another modification of the cup and cone plan has also been tried at the Blaina and Cwm Celyn Iron-works. In the mouth of the furnace was fixed a short hollow cylinder of wrought iron, within which was a second similar short, close-fitting cylinder suspended at the end of a lever, and so capable of being raised or lowered. Immediately below was a stationary cone of cast-iron supported on cast-iron bearers, placed crucially with their ends let into the brick-lining of the furnace. When the inner cylinder was let down, it rested on the lower part of the cone, and closed the mouth of the furnace. The mouth being thus shut, the materials were charged, when the inner cylinder was drawn up, and they fell sliding towards the circumference of this part of the furnace. It was found that the cylinders warped to such a degree as to cause great leakage of the gas, and the method was accordingly abandoned.

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[8] Supplement to Ure's Dictionary of Arts, Manufactures, etc., 1844, p. 217. Vid. Proceedings of the South Wales Institute of Engineers, Jan. 1858, p. 28. Mr. Parry in his paper in this work states that he "has been informed that a similar mode of charging was in use at the Cyfartha Iron-works in the year 1800, the cone being fixed in the throat of the furnace, while the minerals were discharged on its apex from baskets."

[9] Op. cit. p. 218, No. 132, immediately to the left of the letter D.

SOLID MATTER CARRIED OVER WITH THE WASTE GAS.

A considerable amount of fine solid particles or dust is carried over with the gas, and in every case it is necessary to provide suitable means for its occasional removal from the pipes or culverts in which it may be deposited. I am indebted to Mr. E. Riley for the following analysis of the deposit from a culvert used to convey the gas down from the tunnel-head of one of the blast-furnaces at the Dowlais Iron-works. It had been allowed to accumulate during about two years prior to its removal.

Silica	30·33
Sesquioxide of iron	47·05
Peroxide of manganese	1·77
Alumina	8·43
Lime	2·30
Sulphate of lime	4·42
Phosphate of lime	0·75
Magnesia	1·13
Potash	1·80
Soda	0·36
Hygroscopic water	0·93
Copper and antimony	traces
	99·27

I should certainly have expected the presence of some carbonaceous matter in such a deposit, arising from the decrepitation of the coal or otherwise.

EFFECT OF TAKING OFF THE WASTE GAS ON THE WORKING OF THE FURNACE.

Supposing that the waste gas may be conveyed away from the furnace at or near its mouth, without in any way affecting either the gaseous current continually ascending from the twyers, or the descent of the materials charged, it is obvious that not the slightest influence should be thereby produced upon the quality or the quantity of the pig-iron made. Any injurious effect, therefore, upon the working of the furnace which may have been found to result from the utilization of the waste gas, must be due to interference of some kind, either with the ascending gaseous current, or with the descending solid current, as this may be appropriately termed. Now, it may be readily conceived that the adjustment of apparatus to the mouth of a furnace, whether, for example, in the way of simple construction or total closing, would be likely to influence both currents; for, the pressure of the escaping gas might be either increased by obstruction or decreased by contrivances designed for exhaustion, and the solid materials might not become intermixed in the upper part of the furnace in exactly the same manner as previously, owing, it may be, to the charges being now thrown in towards the centre, when the large lumps would roll towards the circumference, and not, as heretofore, thrown in round the circumference, when they would roll towards the centre. These are not imaginary possibilities, but conditions which experience has proved to be influential and important; and in proof the following evidence may be adduced.

Mr. S. H. Blackwell took the management of a furnace, provided with a cylinder 6 ft. in diameter, and other arrangements for taking off the gases.[1] Two evils constantly occurred, "slipping," and "fretting twyers." The stacks were not powerful enough to draw off the gas without a closed mouth, and, accordingly, the cup and cone method similar to that in use at the Ebbw Vale Iron-works was adopted. The beneficial effect was immediate: the furnace worked with great regularity, and carried a good burden; but white iron alone was produced. The burden was lightened, or in other words, the proportion of coke was increased, yet without changing the quality of the iron. The burden was further lightened, and, although the cinder was exceedingly grey, the iron still remained white. A pipe 9 in. in diameter was inserted at the filling place, but with no result. Another pipe was inserted, when some little change appeared. As it was important to obtain grey iron, it was determined to abandon the utilization of the gas, rather than continue to make white iron. The valves of the gas-pipes were opened close to the mouth of the furnace, so as to allow of free and direct communication with the atmosphere, when the iron became grey and the furnace worked with great regularity. Mr. Blackwell correctly ascribed the production of white iron to the increase of pressure caused by the closed mouth; for, the mode of filling was precisely the same when both white and grey iron were made. "So extremely sensitive," he states, "did the furnace appear to be to the slightest restraint upon the free removal of the gases, that even a strong wind blowing into the open box through which the gases were principally escaping would throw the furnace into white iron."

Mr. Blackwell had charge of two furnaces in Derbyshire from which the gases were taken off for the purpose of heating the blast, and which worked with considerable regularity so long as the temperature could be properly maintained. This, however, was not constantly the case, on account of the opening into the gas-flues being so near the mouth of the furnace, that when in certain directions of the wind the gas did not pass off with regularity, or if it came off in sufficient quantity, it was so mixed with atmospheric air that it burned down the passages, and thus occasioned great inconvenience. A wrought-iron cylinder was then inserted in the mouth of the furnace; but the mouths of the furnaces were small, and only admitted of the use of cylinders 4½ ft. and 6 ft. in diameter respectively. The result was quite satisfactory in causing a regular supply of unignited gas. But the furnace with the 4½ ft. cylinder began to scaffold and slip, the twyers were exceedingly troublesome, and the weekly make fell off considerably. After a trial of one or two weeks, the cylinder was taken out, other means were adopted to prevent the ignition of the gas taken off, and the furnace resumed its former regularity. The furnace with the 6 ft. cylinder worked far better, yet not quite satisfactorily; and upon the cylinder burning out, it was not renewed, an arrangement similar to that represented in fig. 80 being now adopted in both

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[1] Proceedings of the Institution of Mechanical Engineers, ante cit. p. 196.

furnaces. Thus modified, they afterwards worked satisfactorily during several years, yielding gas sufficient to heat the blast without any consumption of slack.

Upon the preceding results Mr. Blackwell remarks as follows:— "It was evident from this trial, and from similar results at other works, that the irregularity did not arise from the mere abstraction of the gases themselves; and there was only one other cause to which it could be attributed, viz., the narrowing of the filling part of the furnace; and the question then arose, in what way did this operate? The first suggestion that presented itself was naturally that the effect produced arose from decreasing the area through which the gases generated in the furnace were given off, and thus causing greater obstruction to the free passage of the blast. This explanation was soon found to be untenable." The insertion of a thin cylinder into the mouth of a furnace does not sensibly diminish its diameter; and, therefore, the gas must escape under the same pressure with as well as without the cylinder. Moreover, Mr. Blackwell, in support of the correctness of his conclusion that increase of pressure could not have occasioned the injurious effects in the furnaces abovementioned, adduces the fact that certain furnaces in South Wales work well with closed mouths, "although the area through which the gases are taken off is in some cases not equal to that of a 3 ft. pipe, and much less than the smallest of the cylinders which produced such unfavourable results." Now, in the Welsh furnaces referred to, either the fixed or moveable cone (previously described) was employed, of which the effect is to distribute the materials of the charge round the circumference of the interior of the furnace, as they would be in open wide-mouthed furnaces. Hence Mr. Blackwell infers, "that cylinders in Wales had been productive of much less injurious consequences to the general working of the furnace than those in Staffordshire, because the greater width of the Welsh tops had permitted cylinders of from 8 ft. to 10 ft. to be employed, whilst in Staffordshire only cylinders of much less size were practicable. "The important effect," continues Mr. Blackwell, "produced on the working of the furnace, chiefly by an alteration in the arrangement of the materials in the furnace, is a point of considerable interest, but one to which little attention has hitherto been paid. In practice it has been long known to the best managers of furnaces, that wide tops were desirable, and generally accompanied increased make, but the precise manner in which wide tops acted was not clearly known until the attempt to use the waste gases led to its evident explanation."

It might be urged that the evidence derived from the working of the Welsh furnaces is not apposite, because they may differ considerably from those of Staffordshire in form and dimensions, and that the fuel and materials smelted in the two localities may be dissimilar.

Utilization of the Ammonia evolved from Blast-furnaces.

When raw coal is used as fuel, it is obvious that, during its conversion into coke as it descends in the furnace, the ascending gaseous cur-

rent must contain ammoniacal products. Bunsen and Playfair state that ammonia was present in such abundance as to be sensible to the smell in the gases collected even from the deeper parts of the furnace at Alfreton. They found that for 100 parts of ammonia 3·77 parts escaped along with the gases, while 96·27 parts were contained in the water in the lead tube used for collecting the gas in their experiments, and which resulted from the condensation of the aqueous vapour in the gas as it escaped from the furnace. "The ammonia," they suggest, "may be obtained in the form of sal-ammoniac, and the gas previous to its application as fuel be conducted through a chamber containing muriatic acid. . . . If the solution of sal-ammoniac produced by the condensation of the ammonia be allowed to flow into an evaporating pan, over the surface of which a small part of the flame of the combustible gas is allowed to play, a convenient arrangement of the liquid and of the burning stream of gas would enable us to obtain a constant flow of a concentrated solution of sal-ammoniac as an auxiliary in the manufacture. The advantage of its collection is, that without any further consumption of fuel, or any considerable expenditure of labour, a valuable commercial ingredient would be economized." They computed that 2 cwts. of sal-ammoniac might have been thus obtained every 24 hours at the Alfreton furnace, "without increasing the cost of manufacture, or in the slightest degree disturbing the process of smelting."

Schemes, which are very ingenious and quite practicable on a small scale in the laboratories of chemists, may be impracticable, or at least not economical, on the large scale as manufacturing operations; and, if I do not greatly err, the proposal to obtain sal-ammoniac in the manner above described is one of these. It is certainly to be regretted that such a valuable substance as ammonia should be wastefully dissipated in the atmosphere; but regret will be unavailing unless it can be shown that more money is to be gained by checking an evil than by allowing it to continue, and Bunsen and Playfair have not proved which of these two evils is to be preferred with respect to the collection of ammonia from blast-furnaces.

ON THE BEST FORM OF THE BLAST-FURNACE.

This may be regarded as a *quæstio vexata* in the metallurgy of iron. Is there a best form for all the different conditions under which the smelting of iron is effected—for hot as well as cold blast—with every variety of fuel, from bituminous non-caking coals to anthracite, coke, or charcoal—with every variety of ore, from spongy limonite to dense magnetic oxide of iron—for the make of every description of pig-iron, as white, mottled, and grey—and equally applicable when the waste gas is utilized as when it is allowed to escape into the atmosphere? It will now be perceived that this apparently simple question is one of no ordinary degree of complication. But let us first enquire respecting certain conditions, which must be fulfilled under all possible circumstances.

Descent of the solid materials.—It seems clear that the descent of the solid contents of the blast-furnace should, as far as practicable, take place

regularly, and, consequently, that the form of the interior of the furnace should be such as would be least likely to cause lodgment or sensible retardation in any part. Hence, sudden contraction, or, what is equivalent, sharp angles in the lining, should be avoided. But it is obvious that in the old furnaces, in which the inclination of the boshes was not steep, this condition could not be satisfactorily fulfilled. Accordingly, lodgment, or, as it is technically termed, scaffolding, was of frequent occurrence in such furnaces, an evil sometimes productive of serious inconvenience. Experience has nearly everywhere led to the construction of furnaces of more or less uniform curvature, in some cases even from the mouth to the bottom of the hearth. The form of interior now generally adopted approximates to the cylindrical from a certain distance below the mouth and above the top of the hearth. In some furnaces the shaft is actually cylindrical in the greater part of its course. This modification was introduced first at Dundyvan, in Scotland, and, subsequently, in some other localities, as at Russell's Hall, near Dudley, belonging to Mr. S. H. Blackwell, and Messrs. Cochrane's Works near Middlesboro'-on-Tees.

To the late Mr. John Gibbons, an ironmaster in South Staffordshire, is ascribed the merit of having first recognized the importance and adopted the modern form of the interior of the blast-furnace. He published a pamphlet on the subject in 1839, of which a reprint was issued in 1844.[2] It is in many respects so interesting that I shall not hesitate to extract largely from it. The style of the author is extremely quaint, and I shall, as far as practicable, quote his own language.

"I have had," writes Mr. Gibbons, "ample opportunities of watching the Blast Furnace in its operations, and I have employed them, specially, in *marking the changes effected by the fire in its inner form*, at almost every period, from its being put into blast, to the time when it became necessary to renew the Hearth and the Boshes. The average duration of these in Staffordshire may be stated at four or five years; now, having had under my direct superintendence for many years, and at one and the same time, six Blast Furnaces, it has often been necessary or expedient for me to blow them out, at all intervals, from three months to the time when they would work no longer. By some chance or other, I acquired the habit of observing, with much attention and interest, the changes of internal form before alluded to. I had used to say to myself, 'a fiery finger has written knowledge on these walls; I will try to decypher it,' and in this way I found or fancied many things. The first circumstance, perhaps, that directed my thoughts more particularly to the subject on which I write, was the very rapid destruction that takes place in the Hearth and Boshes during the early period of the Furnace being worked; at the end of six months, it may, I believe,

[2] Practical Remarks on the Construction of the Staffordshire Blast Furnace, &c. Birmingham, 1844, 8vo. pp. 24. The pamphlet seems to be very scarce; and although I have during many years tried to obtain a copy, I have not yet succeeded in doing so. I am indebted for the loan of the reprint to Dr. Merryon. I have not seen the first edition.

be safely stated as a general fact, that both of them have been carried away to the extent of at least a third of their substance. From this time, or about this time, for exact accuracy cannot be attained on such a subject, the destruction becomes gradual, and proceeds more or less slowly, till the Boshes, either in some part of their circle or the whole of it, are obliterated; and this may be called the natural death of the Furnace—it will carry on its operations no longer. The Hearth may be replaced or repaired from without for an indefinite period, but the Boshes are beyond our reach, and when they are gone the case is hopeless—the Furnace must be blown out. This is the first important fact that I observed, and I shall add to it but one other, for it is my object to write as concisely as I can. I observed, then, that in the upper part of the Furnace, from eight to twelve feet downwards from its top, or about a fourth, perhaps, of its total height, the lining bricks were but little changed in their appearance, even at the end of four or five years; lower down, they became superficially glazed, and by degrees were eaten into more and more deeply, forming (so to speak) a self-registering pyrometer that marked accurately enough for all practical purposes, the different degrees of heat to which the lining of the Furnace, in all its parts, has been subjected."

"It appeared to me, then (with a view to the rapid destruction occurring at first), that if I at once *made* the room, which the Furnace *makes* for itself by a rougher operation, I might probably preserve thereby a considerable portion of my Hearth and Boshes; for it was evident, that after a certain period the ravages of the fire, if not suspended, were greatly diminished, and I hoped by *giving* to it, as far as I could, the range that it *forced* for itself, I might lessen its destructive energy—there was no risk in the experiment, and I made it. I put in my Hearth Stones as wide asunder as the pillars of the stack [*i. e.* the pillars which carry the shaft of the furnace] would allow: I cut them upwards from the Twyers to their junction with the Boshes in a diagonal line, so as to bring them into the same, or nearly the same angle with the Boshes, and I certainly found that my purpose was thus far answered. The Furnace lasted longer, the Hearth did not call for repair so soon, and there was this additional advantage, *I arrived at my full burden and average make for months before the accustomed period.* [The italics are mine.] This was my first improvement; others may have done the same thing, or something equivalent to it; but if so, I am ignorant of the fact; most certainly I have no wish to ascribe to myself what does not belong to me, and if in any instance I trespass against the law of '*suum cuique*,' it is unconsciously."

The second alteration, which Mr. Gibbons introduced, and which he regarded as more important than the first, consisted in considerably enlarging the upper part of the interior of the furnace; and he was led to this by reflecting that as the temperature of this part barely sufficed to glaze the fire-brick lining, "no chemical change in the raw materials" could there occur. Hence, he inferred that if he could by some means or other "accumulate heat in this hitherto useless part of the furnace, to such an extent as would let loose the chemical

agencies," he would quicken the smelting process and economise fuel. "As opportunities occurred," he writes, "I did so, but it was gradually; for I am a timid experimentalist, and Blast Furnaces are too costly in themselves, and in their operations, to be treated as playthings." He first scooped the interior of the furnace outwards from the top of the boshes to the mouth, as far as he could do so with safety to the general structure, and "the effect was unequivocal," particularly as to the consumption of coal. The next step was increasing the diameter of the mouth, and 8 ft. Mr. Gibbons regarded as the "proper maximum," with at least four hoppers or filling holes, through which the materials of the charge should be alternately thrown in, so that they might be distributed as evenly and nearly on a level as practicable. Furthermore, instead of the practice then prevailing of beginning to contract the interior from the usual lower termination of the boshes, *i.e.* about 12 ft. or 14 ft. above the bottom of the hearth, he widened it upwards to the height of 30 ft., or more than half its total height, so that the boshes being 12 ft. across, the widest part of the furnace, which became "virtually the crown of the boshes," was full 14 ft.

After blowing out furnaces while working well, Mr. Gibbons found not more than 5 in. or 6 in. of the incline of the boshes left. Hence, by extending the boshes much higher and giving them a steeper slope, he considered that he had "removed them to such a distance from the more destructive agency of the fire, as to make it almost certain that an efficient portion of their upper part will remain, till the furnace becomes incapable of working from some other cause; in fact, till the fire insinuates itself through some by-way or another into the red-work (*i.e.* the outer casing of red brickwork, which in Staffordshire is termed red-work, to distinguish it from the fire-brick work, which is comparatively white.)" The correctness of this conclusion was proved by the fact that a furnace constructed on the principles abovementioned continued 7 years in blast, and, as far as concerns the interior, was in good working order when it was blown out.[3] Estimating the duration of this furnace by the criterion of *make*, after it had been 4½ years in blast, it had "outlasted by a doubled term the longest-lived of its brethren" in the vicinity, and it then, so far from showing any sign of decay, worked better than ever.

The following conclusive numerical results are adduced by Mr. Gibbons in proof of the correctness of his views. Close to a furnace, A (*fig.* 82), constructed on the new principles above stated, was another, B, built in a great degree, though not entirely, on the old model; this was blown by the same engine, with the same volume and pressure of blast as the other; it was under the same management, and fed with the same materials—namely, ironstone and cinder from the refinery, puddling, and mill-furnaces. The work at B during 6 consecutive months was a weekly make of 75 tons,[4] whereas with A during 6 consecutive months (including 3 of the worst in the year) the average

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[3] Op. cit., note [1], p. 30.

[4] The ton here referred to is 20 cwts. of 120 lbs. to the cwt., or that of 2400 lbs. avoirdupois.

weekly make was 100 tons. The best 3 months' work with B was a weekly make of 79 tons, and with A 107 tons. The largest make in a single week with B was 84 tons, and with A frequently 115 tons. The metal was in every case good grey forge-pig. With two other furnaces in which ironstone alone was smelted, the make was much greater even than in A. The reduction in make, when a large proportion of cinder is used, is a point on which Mr. Gibbons lays stress, as he does also upon the fact that he had a very insufficient supply of blast at a pressure only of 1 lb. 13 oz. per square inch. Thus writes Mr. Gibbons:—"I stand upon my facts. Here is my furnace, and here are its performances! Has it, or has it not, considerably exceeded the usual make in Staffordshire, my drawbacks notwithstanding? And if it has, to what cause can you attribute it, other than the modification of its form?"

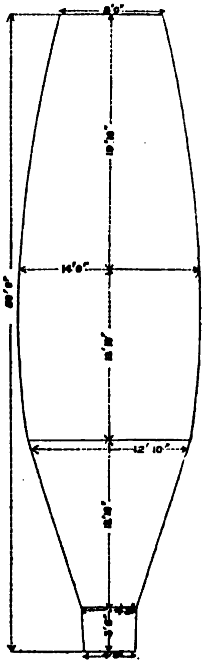

Fig. 82. No. 4. Corbyn's Hall. Gibbons. 4980 cubic ft. solid content.

Another furnace was afterwards built by Mr. Gibbons after the model of A, but 2 ft. were added to its height, about 3 in. to its widest part, and 18 in. to the square of the hearth. This furnace has often made 150 tons per week of grey iron, its average for long periods being 135 tons. It was worked with hot-blast and a large proportion of cinder. Its make was full $\frac{4}{5}$ of No. 1, and the remainder No. 2 and 3, all foundry iron.

Mr. Gibbons gratefully acknowledges the assistance which he derived from Mr. William Gibbons in carrying his principles into practice; and thus quaintly expresses himself concerning innovations in the smelting and manufacture of iron:—"Luckily, too, he [Mr. W. Gibbons] is gifted with an imperturbable temper, and a perseverance that never sleeps, or slumbers, or tires; and the ironmaster who would break up fresh ground has need of it all. The lawyer's love for his precedents is not half so strong as the workman's for his accustomed methods. If the '*Stare super antiquas vias*' be the true wisdom, they are the wisest of men. I can speak feelingly on the subject, for not only at the Blast Furnace have I had much to do in this way, but at the Forge and Mill a great deal more; and, oh, the worry and the fret! the objections 'never ending, still beginning!' the obstacles raised up against you on every side—obstacles with a Hydra-headed life, for strike them down as you may, they are sure to rise, and reappear again and again. Poor Christian in the Slough of Despond was not in so bad a plight as the innovating ironmaster; the toil of Sisyphus was but a type of his; at the last (to be sure) he may lodge his slippery stone upon the mountain top, but his labours are not over, he must continue to guard it, for many and many a day, with anxious eyes, or he will find it rolling down again, he scarce knows how,

urged, as it would almost seem, by invisible fingers." There is much sound practical philosophy in these remarks.

Whatever may be the opinion as to the reasons which Mr. Gibbons assigns for his modif on of the internal form of the blast-furnace, there can be no doub to its beneficial results. It might, however, be urged that the ts of the working of the A and B furnaces do not admit of exac parison, inasmuch as the cubical contents of both were not the e. But, in reply, it may be stated that the difference, which may have existed in this respect, was not commensurate with the difference of make in the two furnaces, while working under practically identical conditions. The hearth of his improved furnace was very small compared with the hearths of many furnaces subsequently erected, especially in this country, and which have been found to work in the most satisfactory manner. Mr. Gibbons seems to have appreciated the importance of a wide hearth; for he states, "I most certainly would place my pillars wide enough asunder to admit of a 5-ft. hearth, at least, when the stones were first put in."[3] In 1843, that is one year preceding the reprint of Mr. Gibbons's pamphlet, a blast-furnace, having a circular hearth 9 ft. in diameter, was erected by Mr. Kenyon Blackwell at the Russell's Hall Iron-works, near Dudley. This was a considerable step in advance. The weekly yield of this furnace was about 175 tons, the largest make at that period of any furnace in South Staffordshire.

One of the characteristic features of Mr. Gibbons's improvement is, the steep inclination of the boshes and the rounding off of the hearth from the twyers upwards, thus avoiding the sharp angles which previously existed both at the top and bottom of the boshes. Now, it is obvious that such an alteration of form must affect in a sensible degree the descent of the materials in the corresponding part of the furnace. There would be less friction on the lining of this part, and, consequently, less inequality in the rate of descent between the external and central portions of the solid contents in this part, and the influence of such inequality would necessarily extend to a considerable distance upwards. Besides, it seems reasonable to suppose that the alteration of form in question would not be without effect upon the ascending gaseous current and upon the distribution of heat, if not also upon the temperature in the interior of the furnace, especially below the boshes.

The decrease in volume which the materials of the charge undergo during their descent through the furnace is a point which demands particular notice. Suppose the fuel to be charcoal or coke—that the ore is of a nature neither to expand nor contract in a sensible degree by heat, as is the case with the magnetic oxides, red hæmatites, and ores previously calcined—and that the flux likewise suffers no sensible change in bulk by exposure to a high temperature, as is the case with lime, and even with limestone—then it seems reasonable to conclude that the internal diameter of the furnace should begin and continue

[3] Op. cit., note [4], p. 27.

pari passu to diminish with the contraction in volume of the descending column forming the solid contents of the furnace. Now, this contraction will coincide with the oxidation of the carbon of the fuel, which commences where reduction of the ore first takes place, and the temperature is sufficiently high to convert carbonic acid by contact with carbon into carbonic oxide. The narrowing, therefore, of the interior of the furnace should be comparatively rapid towards the bottom, where the carbon is most quickly removed in the state of gas, and especially in the zone of fusion, where the volume of the descending column is further greatly decreased by liquefaction. Accordingly, it will be found that modern furnaces of the most approved construction are precisely those in which these theoretical conditions seem to be best fulfilled.

But the rapidity with which the fuel disappears will obviously vary with its nature. Light, easily combustible charcoal, for example, will be much more quickly consumed than dense and difficultly combustible anthracite. The quantity of air, also, blown into the furnace in a given time, or, in other words, the mode of driving, will necessarily be another cause of variation with respect to rapidity of combustion. Whether difference in the temperature of the blast will tend to the same result does not *à priori* appear equally certain; because, with hot-blast there is much less fuel to be consumed for a given yield of pig-iron than with cold-blast, and it does not, therefore, follow that there should be a different rate of contraction in the descending column from that in a furnace working on cold-blast. From these considerations, it will, I think, be admitted that the problems connected with the descent of the solid materials through the blast-furnace are not so simple and easy of solution as at first might have been anticipated. One inference, however, may with tolerable certainty be drawn from them, namely, that the same form of interior of the blast-furnace will not be equally suitable for every kind of fuel.

It has been previously shown that under the conditions supposed with respect to the nature of the charge, there is neither reduction of the ore nor oxidation of carbon to a considerable depth below the mouth of the furnace, and consequently, no sensible decrease in the volume of the descending solid materials. Hence, it might be inferred, that throughout this space the interior of the furnace should be cylindrical, except near the mouth, which it is necessary to contract, in order that, in filling, the materials may be more regularly commingled, and more evenly distributed than would otherwise be practicable. Accordingly, as we have seen, furnaces have been constructed of which the shaft is cylindrical from a certain distance below the mouth to the top of the boshes proper. These furnaces are reported to work very satisfactorily, yet they have but rarely been adopted.

After all, it must be confessed, that experience is the only sure, and, therefore, safe guide with reference to the precise inner form of the blast-furnace best suited for any particular fuel, etc. etc. We have merely to inspect the engravings of the vertical sections of blast-furnaces, which have been erected at different times and in different

localities, to learn how great has been the diversity of opinion as to the question now under consideration, namely, the best form of furnace. But experiments on the construction of great furnaces of this kind must necessarily be very costly, and should not be lightly made, as, in the event of failure, the loss, whether from diminished yield, alteration in the quality of the pig-iron, or increased consumption of fuel, may speedily rise to a large amount.[6]

During the descent of the solid materials in the blast-furnace, it is clear, that somewhere before reaching the zone of fusion they should be thoroughly commingled, in order that the flux may act efficiently and the reduced iron be properly carburized. The materials of the charge may be more or less uniformly mixed at the top of the furnace, if the filling be suitably conducted; and, supposing this to be the case, the form of the interior of the furnace will not, probably, tend to render the mixture less regular. On the other hand, supposing the contrary, then it seems probable that one form of interior of the furnace may induce intermixture of the ingredients of the charge much more than another. In the furnace with a cylindrical interior, it seems least likely that any effect of this kind should occur, although even in such a furnace, especially if it be wide, the rate of descent at the sides, owing to friction, would be somewhat less than towards the centre; and, unless the rate of descent is absolutely the same in every part of the horizontal sectional area of the furnace throughout, the ingredients of the charge will become more or less intermixed in their course downwards. It has been imagined that towards the lower part of the furnace, owing to the more rapid descent of the solid materials of the charge towards the centre than near the circumference, a sort of vortex or succession of vortices is formed, such as is seen in the sand of an hour-glass; but if this were so, it would imply at least occasional interruption in the descending column immediately above the vortex, and, what is equivalent, temporary, and, it may be, slight scaffolding.[7] Now admitting this for the sake of argument to be true, particles would tend to roll from the circumference into the hollow towards the centre, and so commingling might be promoted. The existence, however, of vortices of this kind is, it must be remembered, only imaginary at present, and has not, so far as I am aware, been established by observation.

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[6] Mr. Gibbons has made some pertinent remarks on the danger of scheming in iron-works: thus he writes, "A set of experiment-making workmen would be worse than the plagues of Egypt. The master, too, had better beware of this propensity: it is a dangerous one; and though, perhaps, I have been a little of a schemer myself, I say most devoutly—'The Lord deliver me from this restless and mischief-making race.' In an iron-work, of all places (from the magnitude of our operations, the number and complexity of our processes, and more emphatically, perhaps, from the obscurity in which some of them are shrouded), the projector, with his circumscribed vision and remorseless hand, is the most especially to be dreaded. . . . . Let Science approach, and welcome—we can find her enough to do; peradventure, enough to baffle and confound her. Let her come." P. 33.

[7] Vid. op. cit. by Mr. Gibbons. Appendix, p. 21.—"I do not believe that the materials descend altogether, or on a level, as a piston descends in a cylinder; but that they pass down a kind of vortex or funnel, much as sand does in the hour-glass."

A few years ago Mr. Kenyon Blackwell published a paper containing some judicious remarks on the construction of the blast-furnace.[a] "The proposition," he writes, "laid down by some of the principal writers on the theory of the blast-furnace, namely, that the materials in it, which possess very different specific gravities, descend through the furnace in the same distinct strata as those in which they are spread when introduced at the mouth, is entirely erroneous. Their descent is in vertical lines, moving parallel to each other at different rates, according to their different specific gravities; and this species of motion produces a perfect intermingling of the whole. The internal outline ought to be such as not to interrupt this motion in any part of the descending column, nor by a too rapid contraction of the sectional area of the furnace to arrest the outward portions of the materials, while the internal portions, situated vertically above the hearth, leave the others behind in their passage downwards."

If the descent be in vertical lines, these must of course be parallel to each other; but how such verticality of motion can take place everywhere in an ordinary blast-furnace in which the interior curves considerably outwards, and the mouth and hearth are much narrower than the shaft, does not appear very intelligible. Nor is it clear how the rate of movement should be much affected by variation in the specific gravity of the materials composing the descending column. If, indeed, specific gravity were operative under the conditions supposed, then, in the smelting of dense magnetic iron ore, for example, with charcoal, not much of the latter should reach the lower part of the furnace, owing to the enormous difference of specific gravity between this kind of ore and fuel. But we know that such is not the case; and, *à fortiori*, it cannot be in a furnace working with a much denser fuel than charcoal, such as coke or anthracite, and, for the most part, much less dense ores than compact magnetic oxides, such as limonite, etc. The solid contents of a blast-furnace are packed pretty closely together, especially low down, from the great superincumbent weight, and specific gravity can have no appreciable influence upon the rate of descent. There appears to be some incompatibility between the two statements of Mr. Blackwell, namely, that the materials descend in vertical lines, and, nevertheless, perfectly intermingle.

The size of the materials of the charge is a point which must be specially considered in connexion with the subject of their descent. In Sweden and elsewhere the ore, we have seen, is carefully broken into small pieces, while in this country much of it is thrown into the furnaces in large lumps. The size of the pieces of ore should, no doubt, vary according to its nature: thus, it is obvious that compact, dense magnetic oxide or red hæmatite should be in much smaller pieces than light, spongy limonite, or calcined spathic or argillaceous carbonates. Yet it is a question whether in this country the comparatively light ores are not sometimes used in too large lumps. However this may be, when the ore, fuel, and flux vary much in dimensions,

[a] Journal of the Society of Arts, 4. p. 113. Jan. 1856.

either singly or with each other, it is important to ascertain whether this condition may sensibly affect the descent of the solid materials in the furnace.

If, from the mode of charging, or otherwise, the larger lumps should accumulate to a great extent towards the circumference of the interior of the furnace, and the smaller, consequently, towards the centre, or conversely, it seems plain that the ascending gaseous current must be thereby influenced. Where the larger lumps are, there will be the greatest amount of interstitial space, and correspondingly less resistance to the passage upwards of the gas, so that more gas in the same time will ascend through one part of the furnace than another. This condition, it might have been inferred, would have caused irregularity of action, at least in the same horizontal area, and would have influenced in some degree the descent of the solid materials. Now, of late it has been maintained that the unequal distribution of the components of the charge, especially the ore, may actually occur; that so far from being injurious to the working of the furnace, it is positively beneficial; and that it is determined by the mode of charging.

Mr. Parry, of the Ebbw Vale Iron-works, has given particular attention to this subject. He found that furnaces originally built with tops too narrow to produce the best effects, were improved in their action by a conical charger of small diameter; and that those having the opposite defect of being too wide at the top, might also be benefited to a certain extent, provided the walls were nearly perpendicular, or did not widen rapidly downwards, by employing as large a cone as possible in the throat. By this arrangement he supposed that the minerals must drop close to the walls, and the larger lumps roll towards the axis of the furnace, whereby the ascent of the gaseous current through that part would be facilitated, an effect which he considered in a certain degree to depend upon the concave form of the surface of the minerals resulting from this mode of charging, and the consequent diminished height and resistance there to the upward passage of the gas. "This principle of improving the charging of such defective furnaces," Mr. Parry writes, "is carried out to some extent in feeding open-top blast-furnaces where the gases are lost. The charging-plate is so placed as to prevent the nose of the barrow projecting any distance into the furnace; the minerals being thus discharged close to the edge, the larger lumps roll over to the centre, leaving the smaller at the ring-wall to check the upward current there."[a]

In support of the preceding explanation the following observations have been recorded by Mr. Parry:—" A large-domed furnace was furnished with the same kind of charging apparatus [cup-and-cone] which proved so successful in former instances, but the same derangements occurred [scaffolding, black cinder, inferior iron, etc.] as in the cases where a portion of the gases was collected by a sunk tube in the throat. It occurred to the writer, as the furnace could not be filled

[a] Proceedings of the South Wales Institute of Engineers, 1. p. 31. Jan. 1858.

to within 6 ft. or 7 ft. of the top, and that at that depth it was 13½ ft. in diameter, owing to the sharp sweep of the dome, a new form of furnace altogether was in operation, viz., one of 37 ft. in height, instead of 44 ft., with a mouth 13½ ft. in diameter, and not 8 ft. as before; and that as the minerals cannot lie so close against the smooth sides of the walls as they do, locked and dovetailed into each other in the more central region of the furnace, a freer discharge of the gases up the sides must, as a consequence of this, be expected, and in proportion to the respective circumferences of the mouths, or as 25 to 42. On boring a hole through the side of the furnace, about the boshes, this was found to be the case, but to a greater degree than expected. For 2 ft. in, the coke and other materials were at a white-heat; but a little further on towards the centre, lumps of black blazing coal were found, and ironstone which had not even attained a red-heat. The charging apparatus was now raised 5 ft., and the minerals drawn up an inclined plane to the charging cup, enabling the furnace to be kept full to within a short distance of the old mouth, after which it worked as usual. That diminished height alone was not the cause of irregular working, has since been proved, the furnace having been blown out for repairs, and re-lined, giving to it the form and proportions deemed necessary from the experience gained—the height being now 37 ft., and the diameter of the mouth 7½ ft., or one-half that of the body. The same charger, which failed before, is used, and the furnace, now working five years since the change of form, has turned out a large make of foundry-iron, economises the whole of its gas, and is as obedient to the manager as any closed or open top blast-furnace can reasonably be expected to be."

Ascent of Gaseous Current.—It has been impossible to avoid anticipating this part of the subject to a certain extent under the last head. When we reflect upon the phenomena which take place in the blast-furnace, we might naturally suppose that equality of action in every part of the same zone would be desirable, provided that in every part of the same zone the solid materials descend at the same rate, and have substantially the same average dimensions; and, with these provisos, the supposition, it can hardly be doubted, would be well founded. But, frequently, as we have seen, it is otherwise, at least with respect to the last condition, the lumps of ore especially being very unequal in size. Now, it need hardly be observed that large lumps of ore require a much longer time for reduction than the same weight of ore in small pieces. Hence, if, as previously alleged, it is desirable that the large lumps should roll towards the middle for the reason assigned, namely, to facilitate the upward passage of the gas through the central portion of the furnace; and, further, if, thereby, as is also alleged, every part of every zone is traversed in the same time by the same volume of gas, it is difficult to understand how reduction should be equally advanced in the large central lumps and the smaller pieces of ore towards the circumference. Such a distribution of the ore would seem to indicate that in order to equality of chemical change in every part of the zone of reduction, a greater

volume of gas should in the same time ascend through the central part than elsewhere. But on this point I express myself with some reservation, as it may be contended that large lumps of ore will require a certain time for complete reduction to the centre by carbonic oxide, whatever may be the velocity of the upward gaseous current. The temperature, however, will necessarily increase in a certain ratio with the amount of gas which passes upwards. Mr. Parry asserts that a "state of perfection can exist only when the isothermal lines in the furnace are parallel to the horizon — the temperature of the minerals, at any given height, being the same through the whole horizontal sectional area at that height, and, consequently, arriving at the zone of fusion in an equally prepared state."[1] If my reasoning be correct, for the conditions supposed, this assertion of Mr. Parry cannot be received without qualification. It will be noticed that the question here is not with regard to the accuracy of Mr. Parry's observations, in which I fully believe, but simply as to the correctness of his deductions therefrom.

In order to avoid the charge of incomplete quotation from Mr. Parry's interesting paper, I present the following extract *in extenso*:— "We have seen that if the mouth of a furnace be too wide, the heated gases have a greater tendency to pass up the sides than the centre, thus destroying the horizontality of the lines of equal temperature, and giving them a curved form, having the convex side downwards: hence ores, at different temperatures, and of various stages of preparation, will occupy any given horizontal sectional area of the furnace; these descending and mixing in the zone of fusion, will produce evils in proportion to the extent of the deflection of the curves from an horizontal line. On the contrary, if the mouth of a furnace be too narrow in proportion to the other parts, we may expect an undue proportion of the gases to pass up the centre, leaving the minerals around the sides comparatively unacted upon. It is easy to see that the same evils described in the other case must ensue here, the isothermal lines becoming now concave downwards instead of convex, giving as before, through any horizontal section of the furnace, ores at various temperatures, and at different stages of deoxidation or carburization,[2] according to the depth they have attained in the furnace. The writer has never met, in the course of his experience, such a case in an extreme degree; but it is recorded that at the Dowlais Iron-works a furnace with a 6 ft. mouth and 18 ft. body proved a failure, but that subsequently the mouth being widened to 9½ ft., satisfactory results were obtained, the make being doubled, while the consumption of fuel per ton of iron was reduced to one-half, besides an improvement in the quality of the latter."[3]

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[1] Op. cit. p. 30.

[2] Mr. Parry uses the word "carbonization."

[3] Op. cit. 30. The following information was communicated to the meeting before which Mr. Parry read his paper. It made about 200 tons per week of good forge-pigs for many months previous to its being blown out. The width of the hearth, which at first was 7 ft., had become 13 ft. 6 in., the boshes were completely gone, and scarcely a vestige of its original shape remained.

The practical deductions from the foregoing considerations may be summed up as follows:—When, in any given zone, the solid materials are uniformly commingled, and have the same average dimensions throughout, the ascending gaseous current should equally traverse every part of that zone; but when, on the contrary, the materials, especially the ore, differ much in dimensions in different parts of any given zone, the gaseous current should more rapidly traverse that part of it where the lumps are largest, *i. e.* subject to the reservation previously mentioned, and the assumption that increased velocity and temperature of the upward gaseous current will occasion a corresponding increase in the rapidity of reduction in the ore—an assumption for which proof may be reasonably demanded. By way of corollary, it should also be stated that where, in a given zone, most gas passes, the temperature will be highest. By this increase, both in the amount of gas and temperature, there will be compensation for the otherwise slower reduction of the larger lumps of ore, and the whole of the ore may be reduced in the same zone in the same time; and consequently the descending column of solid materials may reach the zone of fusion in an equal degree of preparation throughout.

Mr. Parry has endeavoured to answer the question, "what form and proportions a blast-furnace should have to produce the best results in quality of iron and economy of fuel, whether worked with open top or covered over for the purpose of saving the gases," by a general formula, which may possibly be correct for the particular kinds of ore, flux, and fuel, constituting the charges at the furnaces, of which he has observed the operation, and upon which he has experimented; but it by no means follows, for reasons already assigned, that this formula should be of universal application to charges of every description whatsoever. In attempting a wholesale generalization of this kind, the largest and most varied experience is required, and the greatest caution should be exercised. Again, with regard to the mode of collecting the waste gas, Mr. Parry has proposed an equally extensive generalization, and concludes that in every case the gas "must be taken from a chamber constructed above the surface of the minerals; for if taken from any practicable point of the furnace, below that surface, injury to a greater or lesser extent follows."[4] Now, unless I greatly err, experience in many localities, both in this country and abroad, has demonstrated that the waste gas may, partially at least, be drawn off even considerably below the surface of the minerals, with advantage and without producing any evil consequences. Let me not be misunderstood. While Mr. Parry may be correct in his conclusion as to a particular method of taking off the gas for a particular set of conditions, with respect to the nature of the ore, fuel, etc., he is not justified in pronouncing so broadly against all other methods with other sets of conditions. Nevertheless the principle which he enunciates of taking off the gas above the surface of the minerals appears sound, and will be probably found to be applicable to furnaces of every description and working under any conditions.

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[4] Op. cit. p. 26.

The formula which Mr. Parry proposes for the best form of the interior of a blast-furnace is as follows:—The diameter of the mouth should be half that of the widest part, and this should be not at a less depth than its own diameter; the sides of the furnace from the mouth to this depth should be formed slightly dome-shaped, in order to give to that region a larger capacity than would be obtained by a conical form. The radius of the curve should be formed by a prolongation of the line representing the greatest diameter; for when it is set at a great angle with this line, as is often done to increase the capacity of the dome, the distortion produced by the sharpness of the curve may leave a segment of minerals unacted upon by the gases in their passage to the mouth, and entail greater evils than would be compensated for by the increased capacity. The curve is continued below the widest part of the furnace till it meets the top of the boshes, the angle of which should not be less than 70°, and start from the point of the twyers. The depth also, from the widest part to the twyers, should not be less than its own diameter, *plus* half the diameter at the twyers.

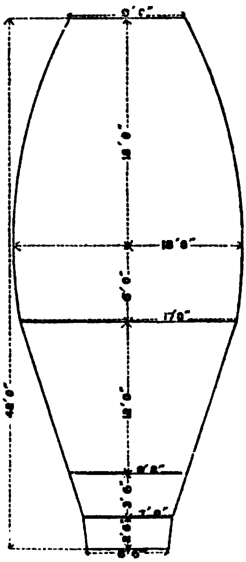

Fig. 83. Parry's model furnace. Proceedings of South Wales Institute. 6600 cubic ft. capacity.

Hearth.—In all old blast-furnaces the hearth was generally, if not always, square or rectangular in horizontal section; and even in not a few modern furnaces this form is retained. Some ironmasters in South Staffordshire have informed me that furnaces with hearths of this construction do not attain their maximum effective power until the hearth, in the course of working, "has cut itself round;" and if this be so, it is not a little surprising that the indication of improvement thus presented should still be occasionally disregarded in that county. In all modern blast-furnaces of generally approved construction, the hearth is circular in section; but I am not in possession of exact comparative experimental data which certainly demonstrate the superiority of the circular over the rectangular hearth, when both have the same capacity.

With regard to the relative dimensions of the hearth, it appears to be established beyond question that until recently the hearth has always been too small, and that diminished yield has been the consequence. Large hearths accordingly are now the rule, at least in this country, although the small hearth is still pertinaciously adhered to in many localities in France and elsewhere. There should evidently be an exact relation in size between the hearth and the rest of the interior of the furnace; but whether the same relation should apply in all conditions with respect to ore, fuel, pressure and temperature of blast, etc., is another question, which experience alone can solve. Under these

circumstances of uncertainty I am unable to present any general formula on the subject.

Mouth.—From what has been advanced concerning taking off the waste gas, and mode of discharging the ore into the furnace, it is evident that the diameter of the mouth is a point of great importance. Irrespective, however, of these considerations, there should obviously be a certain relation between that diameter and the volume of the blast. The mouth may be so narrow as materially to affect the ascending gaseous current from the twyers, and in that case would seriously disturb the working of the furnace; but can it be too wide with reference to its action on this current? Probably not; and its limitation in width must be determined by other circumstances, *e.g.* convenience in filling, proper distribution of the materials of the charge in the furnace, the prevention of loss of heat by radiation, etc. On all these points experience must decide. A mouth which may be large enough for one set of conditions may be too small for another. So far as I know, the only direction which can be given is that the diameter of the mouth must bear a definite relation to the volume of the blast, the minimum being attained when the least further decrease would sensibly influence the escape of the waste gas.

Elliptical Furnace.

It has always been taken for granted that the interior of the modern blast-furnace for the smelting of iron should be everywhere circular in horizontal section, except at the hearth; but a few years ago Mr. Alger, of the United States, proposed and constructed furnaces elliptical in horizontal section, with a tymp, etc., at each small end of the ellipse. This modification in form has been patented in England; and a Company, with a highly respectable Directory, was established in London, with the title of "Alger's Patent Furnace Company, Limited." The capital was 100,000*l.*, with 2000 shares of 50*l.* each. The patentee was to receive 800 shares, and 20,000*l.* in cash.[5] From a printed circular of that Company, dated March 30, 1859, I give the following extracts concerning the working of two circular furnaces belonging to the Hudson Iron Company, U. S., which, in the autumn of the year preceding, had been altered, as far as practicable, into the elliptical form:—"We made our first castings on the 27th November, 1858, and to the 31st December had made 1524 tons, about 900 tons of which were extra No. 1 of a superior grade. 1427 tons were made in December, which is about 300 tons more than our furnaces ever made in one month, on the start, and very much better iron." Mr. Alger, in a letter dated February 24, 1859, states, "We are now making over 30 tons (say 33[6]) per day, with one of our furnaces, showing their joint capacity for making about 420 to 450 tons per week (1900 tons per month), with less coal than before, when we made 250 to 300 tons per week, same stack and machinery. The iron is improved in quality." There is

[5] From the Prospectus issued by the Company.

[6] The weight of the ton is not given. It was probably 2240 lbs.

nothing very wonderful in this, with respect to yield; nevertheless the following conclusion appears in the circular above mentioned:— "These results prove beyond question the very great advantages, as regards quality, economy, and quantity, to be obtained by altering old furnaces into the elliptical form, which may be done at comparatively trifling expense; and at the same time point out most clearly the enormous gain that would result from the full introduction of the patented principle." This, it need hardly be remarked, is the usual style of language employed by promoters of a patent company, and it will no doubt be estimated at its proper value. With regard to make, it is only necessary to state that the Dowlais Iron Company, and Messrs. Schneider, Hannay, and Co., have produced more than 600 tons, and the Aberdare Company 400 tons per week from circular furnaces. It may be somewhat more difficult and more costly to effect the elliptical transformation of existing circular furnaces than the Directors of the Alger Company suppose. As to improvement in quality, evidence more decisive than mere assertion is required; and so also with regard to the alleged economy in fuel, which is stated to be 25% for the same make in circular furnaces. The cost of construction of an elliptical furnace, capable of producing from 400 to 600 tons of pig-iron per week, is declared to be only about half that of furnaces of the old form, in proportion to yield of pig-iron. It is far from my intention by these remarks to pronounce dogmatically against Alger's principle, which can only be tested by carefully conducted experiments. On the contrary, I think it is worth a fair trial, although I fear that it would be difficult to construct a large elliptical furnace as durable as a circular one. There is necessarily a limit to the diameter of a circular furnace, owing to the impossibility of injecting an efficient blast into the central mass; but in an elliptical furnace this difficulty does not equally exist; and the same mass of solid materials would be included within a far less superficial area of interior than in two or more circular furnaces, having together the same cubical contents as the elliptical one.

In July, 1860, I received from Mr. M'Kenzie, of the Dundyvan Ironworks, a lithograph drawing to scale of a large elliptical furnace which he claimed as his own design; but I will not venture to offer even an opinion whether he or Alger is entitled to the merit of originality with respect to this so-called invention. In the Russian department of the International Exhibition of 1862 were models of long rectangular furnaces with a row of several twyers on each side. Furnaces of this kind were reported to have been erected for smelting copper-ores in Perm, and to have been in operation during about 1½ year with success; and if I mistake not, it was proposed to smelt iron in similar furnaces, but I do not know whether this has actually been done. They are known as the Rachette furnaces.

I may here state that Mr. Levick, of the Blaina and Cwm Celyn Ironworks, began several years ago to erect a circular blast-furnace of much larger size than any previously or now in existence; but he ceased to proceed with the work when only about half completed.

as I saw it in 1859, and no further progress has been made. The dimensions are 66 ft. 10 in. in height, 14 ft. wide at the filling-hole or mouth, 24 ft. across the boshes, and 9 ft. wide at the hearth. There are 6 twyer arches, and it is intended to be blown with 7 twyers, 1 in each arch, and 1 in the fore part or front. It is to be cased from top to bottom with boiler-plate. It is to be fitted with the cup-and-cone arrangement, and the waste gas is to be utilized. At Messrs. Bolckow and Vaughan's works there are furnaces 75 ft. high. The higher the furnace, the better, I should suppose, so long as the materials of the charge, especially the fuel, are not crushed, and the blast is not sensibly impeded; for the upper part of the furnace will act as a Siemens' Regenerator, hereafter to be described under the head of Puddling, and heat will necessarily be thereby economized.

MISCELLANEOUS DETAILS CONCERNING THE BLAST-FURNACE AND ITS WORKING.

I do not propose to present such a minute and elaborate description under this head as may be found in some foreign treatises on the blast-furnace, being persuaded that for purely practical men they would be superfluous, and that for purely scientific men they would have no interest.

Blowing-in a Blast-Furnace.

As an example of the mode of blowing-in a blast-furnace, I present a description of the process adopted at the Ebbw Vale Iron-works, for which I am indebted to Mr. George Parry.[7] Half a ton, or a ton, of old timber is put in the bottom, to a height of 3 ft. or 4 ft., and then 18 barrows of coke, of 7 cwts. each. Over this are introduced regular charges of coke, limestone, and a very light burden of ore. When the furnace is thus filled to about $\frac{1}{3}$ of its height the wood at the bottom is ignited. The fire slowly ascends through the mass, and when the surface has become incandescent the charging is resumed, until the furnace is $\frac{2}{3}$ full, the burden of ore being very gradually increased up to that required for the production of good grey iron in the ordinary working. The furnace is now left to itself until the fire reaches the surface of the minerals, after which it is filled to the top with the regular charges. At this time, the 18 barrows of coke and the timber having been pretty nearly consumed, the blast is turned on to the extent only of about $\frac{2}{3}$ of the volume to be subsequently used. This continues for a day or two, after which the valves through which the blast passes are gradually open to the full.

When the furnace is intended to work with a close top, the hopper [of the cup-and-cone arrangement] may be adjusted after filling the furnace, or the latter may be filled by means of the hopper.

The old method of blowing-in furnaces, called the "scaffolding" system, is now seldom resorted to. In this system a grate of bars is

[7] July 29th, 1863.

made across the hearth, on a level with the top of the dam-plate, to support the fuel, of which much more is used than stated above in the other method. The fire is kept burning while the furnace becomes gradually filled, and when the ore begins to appear on the grate the bars are withdrawn, the superincumbent mass falls down, and the blast is then put on.

Labour required in the Management of a Blast-Furnace.

In South Staffordshire there are three men to each furnace; one keeper, one hot-air man, and one filler. Other men, such as coke-wheelers, limestone-breakers, etc., assist at the operation of casting, or, as it is termed, the cast.

Tapping.

The fore part below the tymp is opened before each cast, the blast having been first stopped. The tapping-hole is next opened by driving in a crowbar with a sledge. The metal flows along the channels prepared to receive it, and after it has run slag follows, and accumulates in a shallow circular hole at the bottom of the cinder-fall, called in South Staffordshire the "roughing-hole." A round piece of iron, broader at the bottom than the top, is previously set upright in the middle of the roughing-hole, so that the slag may accumulate round it, and after solidification may, by its means, be raised by a crane, put on a truck, and sent to a distance to the cinder-mound, to be there thrown away.

Formerly, instead of the cinder being allowed, as now, to run into trucks, it was allowed to flow into a roughing-hole, from which it was removed from time to time as occasion might require.

After the cast the blast is put on full, when immediately a very large amount of flame, accompanied with innumerable sparks, issues from below the tymp. The flame is yellowish-white, and not blue like that of carbonic oxide. There is also much white smoke, which partly condenses on the surface of the fore part of the furnace, forming a whitish coating. The opening of the fore part is stopped by ramming clay well in, and a plate of iron is laid so as to keep it firmly down.

The preceding statements with respect to flame are founded on my own observations of blast-furnaces in South Staffordshire. In all the blast-furnaces belonging to the Ebbw Vale Company and at Blaina, which I have particularly observed, a considerable amount of flame is always issuing from under the tymp. This is caused by the more forward position of the dam in the Welsh as compared with those of Staffordshire; and in the former flame is purposely allowed to escape, as the slag would be apt to become too thick at this part of the furnace, if it were not kept well heated by this flame. The colour of the flame, to my eye, was very yellow, as though from the presence of soda.

The appearances of the metal as it runs from the furnace are to a certain extent indicative of its quality. Thus, in the case of white iron there is much scintillation, while there is none in the case of grey iron, the surface of which, in South Staffordshire, I have heard

designated as "creamy;" but it is vain to attempt to convey accurate notions on such points by written description, however elaborate.

The metal may vary considerably in quality at different levels in the hearth; and as in tapping no intermixture is effected, this difference appears in the pigs after solidification. I have seen three varieties of pig-iron, very distinct from each other in respect of degree of greyness, obtained from the same furnace in the same cast. This sufficiently proves that the uniformity of action in a blast-furnace is not necessarily ensured under conditions which, so far as means are afforded of observing on the outside, appear to be absolutely identical.

Sand-Bed for Casting.

The sand-bed extends from below the cinder-fall to a considerable distance in front of the furnace. In some works it is fully exposed to the weather, and in others it is protected by a roof. It slopes gradually from the furnace, and a series of parallel furrows is made of the shape of the pigs intended to be cast, with their long axis directed towards the furnace, sufficient walls of sand being left between the furrows to form barriers strong enough to resist the pressure of the molten metal. The ends of the furrows in each row communicate with a transverse channel in the sand; and all these transverse channels are connected with a long main channel running from the tapping-hole to the bottom of the sand-bed on one side. At first it is only the lowermost row of furrows, *a*, that is connected with this main channel, the communications between it and the other rows being subsequently made in succession by the removal of sand barriers purposely left. The metal flows first into the lowest, or most distant row, and when the furrows in this are filled, communication is stopped between the transverse feeding and main lateral channels by putting firmly down an iron spade, *c*, and throwing sand against it. Thus the furrows in all the rows are filled in succession, the metal flowing last into those nearest the furnace. The accompanying diagram will render the description readily intelligible. In a sand-bed of this kind at the Coalbrook Dale Iron-works, in the Cwm Celyn, belonging to Mr. Levick, there were 6 rows, and 28 furrows or moulds for the pigs in each, but the number will of course vary according to circumstances. The transverse feeding channels form the sows. The names of pig and sow are fancifully suggested by a sow feeding her litter. After the cast sand is strewn lightly over the surfaces of the pigs by throwing it from a shovel, in order to diminish the effect of the radiant

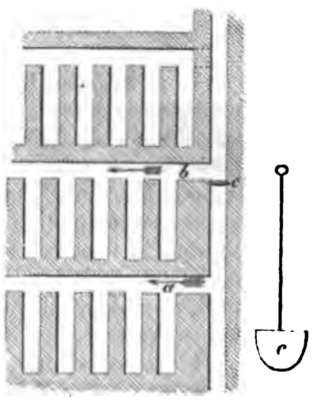

Fig. 84. Diagram of sand-bed for casting. The shading is only for distinctness.

heat. In some works—as at Dowlais, Ebbw Vale, etc.—sand-beds are not used, and the metal is run into pig-moulds of cast-iron. In South Staffordshire tapping usually takes place at intervals of 12 hours. At the Ebbw Vale Iron-works it takes place at intervals only of 4 hours, so that the men are kept more regularly at work than in South Staffordshire.

Derangements in the Working of the Blast-Furnace.

The blast-furnace, to persons not practically acquainted with its working, may appear a very simple kind of apparatus, and not likely to get out of order. But it is far otherwise; and to be managed with success requires much skill, which can only be acquired by long experience. It is, in reality, extremely sensitive, its action being affected by apparently trifling causes. Of this some examples have been adduced in considering the utilization of the waste gas. It is liable to serious disorders, which demand prompt and energetic treatment, and these will now be described.

Scaffolding and slips.—Scaffolding has already been several times alluded to and curtly defined. It consists essentially of a lodgment of a mass of the solid materials in some part or other of the interior of the furnace. The form of the interior, as might be anticipated, has considerable influence in inducing the evil in question; and, accordingly, experience has demonstrated that, *cæteris paribus*, furnaces of one form of interior are more liable to it than those of another. Sharp angles, as in the old furnaces, with very wide and flat boshes and contracted hearths, must obviously be favourable to scaffolding. But it may occur in furnaces of the most approved form in which there are no such angles, the curvature of the interior being gradual and regular from top to bottom, and it may then depend upon several causes, separately or conjointly. The ore and flux may not be properly adjusted, so as to produce a sufficiently fusible slag; the ore may be what is termed very refractory, and be employed in lumps too large to admit of a suitable degree of contact between it and the flux; or the proportion of fuel may be such as not to develope the requisite amount of heat for the formation and liquefaction of the slag with due rapidity. The fuel may be bad, as in the case of coke, which is too friable to resist the superincumbent weight, and which becoming to a large extent reduced to powder impedes the upward gaseous current from the twyers. The effect of this is to lower the temperature where the passage of the gas is thus checked, and, as a consequence, to thicken the slag and produce an agglomerated mass. Whatever be the cause, scaffolding may occasion great mischief. As the solid materials under the agglomerated mass constituting the scaffold descend, the latter may suddenly give way and drop down, or, as it is technically termed, "slip."

But agglomerated masses may occur without producing scaffolding, properly so called, and to such an extent indeed as to "gob up" the furnace and stop its working. A striking example of such gobbing up is presented by the blast-furnaces in South Wales fed with anthracite as the fuel. The Welsh anthracite decrepitates when heated, and some varieties in a really surprising degree. Thus, I have received

specimens from Mr. Waring of Neath, which on the application of sudden heat were reduced to absolute dust. In the Ystalyfera blast-furnaces, worked with anthracite, the accumulation of small particles of anthracite becomes so great as effectually to obstruct the passage of the blast, and, when this takes place, the only remedy is to cease from charging and keep up the blast, when, as the solid materials descend, the fine particles of anthracite are blown out in a continuous volcano-like stream of sparks, and fall down round the mouth of the furnace. I was present during this operation, and was not a little surprised at the large amount of particles which thus accumulated. But Mr. Budd informs me that the great difficulty which he experienced in the use of anthracite arose from the running together of the slag and decrepitated particles of anthracite into infusible masses, and the consequent gobbing up of the furnace. This difficulty has hitherto proved insurmountable. He has tried increasing the pressure of the blast to 5 or 6 lbs. per square inch and the temperature to 800° F., but without success.

Valérius has given the following graphic description of the symptoms due to the gobbing up (*engorgement*) of one of the blast-furnaces at Seraing, in Belgium, working with coke.[8] "Continual slips and suspension of charges during 4 hours or more; the furnace so 'wild' that flame and slag escape with violence from the fore part in spite of the greatest efforts to keep them in; twyers embarrassed by hardened masses in the hearth; obstruction in the twyers gives way after several attempts to force a passage for the blast, which cannot ascend in the furnace. Tapping is attempted: after having in vain during several hours struck heavy blows with a sledge-hammer [*mouton*, heavy mass of iron like the monkey in a pile-driving engine] in order to pierce a tapping-hole at the usual height, an opening is at length effected a foot higher, followed by the escape of a little black thick slag; haste is made to free, as far as practicable, the hearth, and the blast is put on. Half an hour afterwards the slag has reached the twyers; efforts are made to cause it to flow out, but it is only after heavy blows that crowbars can be driven into the front of the hearth; these are pulled out by means of a crane, and are found to be hardly red-hot at their ends; scarcely is the slag set free than it is again forcibly ejected from the opening at the fore part, because the blast is too much obstructed to take its ordinary course. These efforts are continued for about 24 hours before the gobbing up is mastered, but it is only after the lapse of 15 days that the furnace again bears its usual charges. During the whole period of the gobbing up only feeble blue flames proceed from the mouth. Cooling at the mouth is even observed whenever the furnace works with difficulty. Thus while, in the event of an extraordinary descent of the charges, there is difficulty with a furnace in good working order in distinguishing the materials at the depth of 6 or 7 ft. below the mouth, they may be easily seen at the depth of 15 ft. when sensible cooling occurs."

Valérius records with much minuteness several accidents of this

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[8] Traité Pratique de la Fabrication de la Fonte, 1851, p 490.

kind which have occurred at the [illegible] furnaces, and in some instances suddenly. He describes the case in which a portion of the lining above the boshes gave way and appeared in the hearth; but the injury proved only temporary, and the furnace was kept in blast with advantage.

In accidents like the preceding it must be left to the furnace manager to ascertain the cause and determine upon the necessary remedy. Generally, the burden of ore should be diminished until the obstruction is removed, and then, if the fault be found to proceed from the nature of the charges of ore, the mixture of ores, if mixtures be employed, must be varied accordingly; and a knowledge of the composition and reducibility of the component ores respectively will be essential. On such points practice will be the only certain guide, although theory may prove of the highest value in leading to a correct judgment with the least expenditure of time and money.

Indications of the Working Condition of the Furnace, derived from the Characters of the Slag.

To a practised eye the characters of the slag will furnish unequivocal signs of the working condition of the furnace. But in this case again no amount of verbal description, however minute, will suffice to convey accurate and available information in the management of a blast-furnace. Judgment respecting the slag is founded on the manner in which it flows from the furnace, and on the appearances which it presents after solidification.

It should be neither too thin nor too thick, and should run in an uninterrupted and somewhat viscous little stream.

With respect to the characters of the slag after solidification there is much to be said. In the First Part of the Metallurgy I have considered slags generally with great detail, especially as to fusibility in connection with composition; and in this place I propose only to examine certain points relating to slags, which specially apply to the smelting of iron. The composition of the slag must obviously vary with the nature of the foreign matter in the ore, and in a minor degree also with that of the ashes of the fuel. But, as there are essentially only two kinds of fuel, namely coal or its derivative coke, and wood or its derivative charcoal, and as the composition of the ashes of each is pretty constant, only two kinds of flux could possibly be required to fuse the ashes of these fuels respectively. The ashes of coal, with the exception of oxide of iron which is supposed to be reduced, for the most part consist generally of silicate of alumina; and that is readily fluxed by limestone. The ashes of wood, on the other hand, generally require silica as a flux. But the amount of ashes in wood is, with few exceptions, so small in comparison with that of the ashes in coal, especially when the relative quantities of the two fuels needed to produce a given weight of pig-iron are taken into account, that, so far as concerns the flux, it may be practically disregarded.

A very large number of analyses of the slags produced in smelting of iron in blast-furnaces has been published; but not a few of them are worthless for all practical purposes from their not being accom-

panied with sufficient descriptive notices, either with respect to their physical characters, or the working conditions of the furnace from which they have proceeded. Moreover, in a large proportion of the published analyses the composition is substantially the same. Hence, I shall not insert copious tables of these analyses, the effect of which is rather to bewilder than impress the mind of the reader, but shall present such a selection as I conceive will most tend to elucidate the subject.[9]

ANALYSES OF BLAST-FURNACE SLAGS.

Slags composed according to the Formula $R^2O^3,SiO^3+2(3RO,SiO^3)$.

I have very often found these slags at the furnaces of South Staffordshire, both cold- and hot-blast; and they are frequently produced in other localities.[1] Occasionally they occur beautifully crystallized in small square prisms,—transparent, translucent, or opaque,—of about 2·91 in specific gravity,—about equal to felspar in hardness, *i. e.*, No. 6 of the usual scale of hardness adopted by mineralogists,—yellowish-brown in colour,—and easily frangible. Many of the prisms have their angles truncated by planes, making equal angles with the adjacent faces of the prism. In two or three instances I have found crystals of this slag very large comparatively, opaque, and having the edges both lateral and terminal replaced by planes. The slag is completely decomposed by hydrochloric acid, with the separation of gelatinous silica, and the evolution of a little sulphuretted hydrogen. $R^2O^3 = Al^2O^3$, and $RO = (Ca, Mg, Fe, Mn)\,O$. Potash is also present, in the proportion of about 1% or 2%. In the process of analysis on igniting the silica, after washing and desiccation, I have generally noticed a slight odour of sulphur. The sulphide present, which occasions the evolution of sulphuretted hydrogen on the addition of an acid, is believed to exist in the state of sulphide of calcium. The slag is regarded as very good and suitable in all respects. The following series of analyses will sufficiently exemplify the composition.

	I.	II.	III.	IV.	V.	VI.
Silica	39·52	38·05	38·76	37·63	37·91	42·06
Alumina	15·11	14·11	14·48	12·78	13·01	13·05
Lime	32·52	35·70	35·68	33·46	31·43	32·53
Magnesia	3·49	7·61	6·84	6·64	7·24	1·06
Protoxide of manganese	2·89	0·40	0·23	2·64	2·79	2·26
Protoxide of iron	2·02	1·27	1·18	3·91	0·93	4·94
Potash	1·06	1·85	1·11	1·92	2·60	2·69
Sulphide of calcium	2·15	0·82	0·98	0·68	3·65	1·03
Phosphoric acid	..	..	..	..	..	0·19
	98·76	99·81	99·26	99·66	99·56	99·81

[9] Only last year a M. Ch Mène communicated a paper on blast-furnace slags to the French Academy, and prefaced it with the remarkable statement that these slags have been but little studied! This author would have acted wisely if he had studied the literature of this subject before venturing to make such an unfounded statement to the Academy. Vid. Comptes Rendus. 1862. 54. p. 214.

[1] Vid. Report on the Crystalline Slags. By Professor W. H. Miller, of Cambridge, and the Author, to the British Association in 1846. Brit. Assoc. Rep., published 1847, p. 351 et seq.

Nos. II., III., IV., VI. were analysed by myself, and Nos. I., V. by Mr. David Forbes in my laboratory.

No. I. was from one of Mr. Philip Williams's cold-blast furnaces working with coke, at Wednesbury Oak, near Tipton, South Staffordshire. Nos. II., III. were from hot-blast furnaces working with coke, near Dudley. Nos. IV., V. were from Messrs. Blackwells' hot-blast furnaces working with coke, Russell's Hall, near Dudley. When No. IV. was produced, the furnace was considered to be working unsatisfactorily from some interruption to the course of the blast. No. VI. was brought by Mr. S. H. Blackwell from a hot-blast furnace, working also, I believe, with coke, named La Providence, at Marchienne, Charleroi, Belgium. All the analyses were made in the years 1845-6. In Nos. I., V., VI. the sulphur was oxidized by fusing the slag with a mixture of nitrate of potash and mixed carbonates of potash and soda prepared by the calcination of the double tartrate of these bases or Rochelle Salts; and in Nos. II., III., IV. it was oxidized by very strong nitric acid. In all the analyses by the first method a much larger proportion of sulphur was found, and I am disposed to think that these results are more correct than those obtained by the second method.

These slags approximate closely in composition to the natural mineral, Humboldtilite, with which Mellilite and Somervillite are now regarded as identical in species, the ratios between the oxygen of the R^2O^3 and RO bases and the silica being nearly as 1 : 2 : 3, *i. e.*, the oxygen of the silica is equal to that of the bases, and the oxygen of the RO bases is double that of the R^2O^3 bases.[1]

The same mass of slag of the preceding composition will frequently be found vitreous in one part, where cooling has taken place most rapidly, as at the exterior, and crystalline in another; and the colours of these portions may differ in a striking degree. While the crystallized portion is yellowish-brown, the vitreous or amorphous portion may be blue, or brownish-black.

The following analyses of slags from the blast-furnaces at the Dowlais Iron-works were made by Mr. E. Riley, while employed there as chemist.[2] They are substantially similar in composition to those which have just been considered. Every day during 7 consecutive days a portion of slag was run into a ladle from each furnace, and an average sample of 200 grains prepared from each portion. At the end of the week three several samples from each furnace, respectively, were carefully mixed by trituration; and from each mixture a sample was prepared for analysis. The numbers in the uppermost horizontal column refer to the numbers of the furnaces, respectively. The furnaces from 1 to 16 inclusive were making common white forge pig; and only the furnace No. 18 was making grey or foundry iron. All the furnaces were on hot-blast. By "mean" is understood the average

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[1] Handb. der Mineralchemie. Rammelsberg, 1860, p. 731.

[2] These analyses have been published in the Proceedings of the "Society of Engineers," Jan. 1862. They were, however, communicated to me, with the consent of the Trustees of the Dowlais Works, Nov. 12th, 1859.

result of the 13 furnaces; and "average of 13 furnaces" is the result of the analysis of a mixture of equal weights of slag taken from every furnace on one day.

	1.	3.	4.	5.	9.	10.	11.	12.
Silica	39·09	42·52	41·30	44·88	42·08	43·68	42·45	41·08
Alumina	17·14	14·96	16·21	15·51	14·19	16·25	14·30	13·65
Protoxide of iron	2·07	3·62	2·65	6·91	2·35	1·33	2·04	1·29
Protoxide of manganese	1·15	1·50	1·10	1·67	1·59	1·15	1·22	1·02
Lime	31·95	30·04	30·55	23·81	31·55	28·57	30·89	34·32
Magnesia	4·31	3·95	4·42	4·38	4·67	4·42	5·32	4·65
Potash	1·98	2·06	2·26	1·98	1·73	2·21	2·04	1·75
Calcium	1·64	0·85	1·20	0·59	1·37	1·29	1 04	1·22
Sulphur	1·31	0·68	0·96	0·47	1·10	1·04	0·83	0·98
Phosphoric acid	0·22	0·41	0·13	0·43	..	0·10	0·10	..
	100·86	100·59	100·78	100·63	100·63	100·04	100·23	99·96
Metallic iron %	1·61	2·81	2·06	5·37	1·81	1·03	1·58	1·03

	13.	14.	15.	16.	18.	Mean.	Average of 13 Furnaces.
Silica	45·23	42·57	40·02	40·69	38·48	41·85	43·07
Alumina	11·55	13·12	14·71	14·82	15·13	14·73	14·85
Protoxide of iron	3·08	3·48	2·52	2·19	0·76	2·63	2·53
Protoxide of manganese	1·02	1·18	0·91	1·04	1·62	1·24	1·37
Lime	32·09	31·35	32·27	32·60	32·82	30·99	28·92
Magnesia	3·78	4·44	5·47	4·63	7·44	4·76	5·87
Potash	1·53	1·79	1·72	1·71	1·92	1·90	1·84
Calcium	1·04	0·89	1·31	1·29	1·23	1·15	1·01
Sulphur	0·83	0·71	1·05	1·03	0·99	0·92	0·89
Phosphoric acid	..	0·17	0·25	..	0·15	0·15	traces
	100·15	99·70	100·23	100·00	100·54	100·32	100·35
Metallic iron %	2·39	2·70	1·96	1·70	0·57	2·04	1·97

The following analyses of slags from the Dowlais Blast-furnaces are also by Mr. E. Riley.

	I.	II.	III.	IV.
Silica	43·59	46·34	40·92	45·60
Alumina	14·78	15 47	14·85	15·70
Protoxide of iron	1·06	3·92	1·57	8·03
Protoxide of manganese	1·41	1·33	0·97	1·40
Lime	31·40	24·65	32·29	21·65
Magnesia	4·66	5·55	4·85	4·85
Potash	1·57	2·38	1 83	2·03
Soda	0·34	..	..	..
Sulphide of calcium	1·93	0·79	1·61	0·65
Phosphoric acid	..	traces	..	..
	100·74	100·38	98·89	99·91

I. Grey cinder, June 27th, 1854. The charge of ore consisted of 1 part by weight of red-ore (red hæmatite), 1 of Northamptonshire ore, and 2 of Welsh mine (argillaceous ore of the coal-measures).—II.

Stony grey cinder, Aug. 16th, 1854.—III. Black-brown cinder, from No. 13 furnace, Aug. 17th, 1854. A small quantity of lime was lost in this analysis.—IV. Green cinder, from No. 6 furnace, Aug. 3rd, 1854. The charge of ore consisted of 3 parts by weight of Welsh mine and 1 of red ore.

SLAGS APPROXIMATING TO THE FORMULA $R^2O^3, SiO^3+3(2CaO, SiO^3)$.

The following analysis of a slag, which I found at the Russell's Hall blast-furnaces, near Dudley, has been made by Mr. Dick in my laboratory. It is extremely tough and difficultly frangible, contrasting remarkably in that respect with slags of the formula $R^2O^3,SiO^3+2(3RO,SiO^3)$. It consists of an agglomeration of small radiating crystalline masses, and is light yellowish brown grey in colour. It is only partially decomposable by hydrochloric acid.

		Oxygen.
Silica	47·08	24·92
Alumina	12·91	6·01
Lime	29·92	11·24
Magnesia	4·79	
Protoxide of iron	1·00	
Protoxide of manganese	2·20	
Potash	0·87	
Sulphide of calcium	1·78	
Phosphoric acid	0·05	
	100·60	

I have several times found slags at the South Staffordshire blast-furnaces precisely similar in external characters, and, I have little doubt, of nearly identical composition; but I cannot speak with certainty on this point, as only one specimen of such slags has been analysed. They are, however, comparatively rare. Their quality is considered good.

The next analysis, Professor C. Ullgren's, is of a slag from a blast-furnace at Edsken, in Sweden, where excellent pig-iron suitable for the manufacture of steel by the Bessemer process was produced. Charcoal was the fuel. The relation between the oxygen of the silica and that of the bases, inclusive of alumina, is nearly the same as in the last slag; but the relation between the oxygen of the alumina and other bases is very different.

		Oxygen.
Silica	46·371	24·077
Alumina	4·301	2·013
Lime	38·640	14·715
Magnesia	7·400	
Protoxide of iron	0·950	
Protoxide of manganese	1·860	
Potash	0·300	
Soda	0·138	
Copper	traces	
Sulphur	0·030	
Phosphorus	traces	
	100·000	

Lindauer, in a compendious and well tabulated series of slags, produced in smelting iron in various localities, has given an example of a slag of this formula from Siegen.[4] It is described as vitreous, flatly conchoidal (flachmuschlig) in fracture, and leek-green in colour; and it accompanied the production of grey iron. Its composition was as follows:—

Silica	43·40
Alumina	12·20
Lime	18·13
Magnesia	4·50
Protoxide of iron	10·99
Protoxide of manganese	5·80
Sulphide of calcium	3·97
	98·99

According to one of the methods of notation described in the First Part of the Metallurgy, he represents its composition by the formula $AS+R^2S^3$, which is the same as that given above.

A slag somewhat similar in composition to that above described, of which Mr. Dick determined the composition, has been analysed by Mr. David Forbes in my laboratory. It was brought by Mr. S. H. Blackwell from the hot-blast furnace, called L'Espérance, at Seraing, in Belgium. It was brown, porous, and confusedly crystalline. It was only partially decomposable by hydrochloric acid.

		Oxygen.	
Silica	55·77		28·97
Alumina	13·90		6·49
Lime	22·22	6·24	
Magnesia	2·10	0·81	
Protoxide of manganese	2·52	0·56	8·39
Protoxide of iron	2·12	0·48	
Potash	1·78	0·30	
	100·41		

It approximates to the formula $Al^2O^3, SiO^3+4CaO, 3SiO^3$.

Slags approximating to Aluminiferous Augite in composition.

Many years ago I received two beautifully crystallized specimens of these slags from M. Krantz, the well-known mineral collector. They were from the Olsberg furnaces on the Rhine, which, I presume, were worked with charcoal. One (A) contains a drusy cavity with projecting crystals, which, according to Professor W. H. Miller, appear to belong to the oblique prismatic system; but their surfaces are not sufficiently bright for measurement with the reflective goniometer. They have a single face, which is not at right angles to the axis of the prism. They have the hardness of apatite, *i. e.*, it is equal to 5. The slag is excessively tough and difficult to break. The other specimen (B) is a mass, exhibiting a radiated crystalline struc-

[4] Compendium der Hütten-Chemie mit besonderer Anwendung auf die Metallurgie des Eisens. Prag. 1861. p. 278.

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

[illegible]	[illegible]	[illegible]

[illegible]

[illegible]

[illegible] transparent [illegible] by

hydrochloric acid. It was analysed by myself, and the results are as under:—

					Oxygen.	
Silica	28·28	28·36	..	28·32	..	14·71
Alumina	24·24	24·27	..	24·24	..	11·33
Lime	40·39	..	39·96	40·12	11·27	
Magnesia	2·94	..	2·62	2·79	1·08	
Protoxide of manganese	..	..	..	0·07	0·01	12·53
Protoxide of iron	..	..	..	0·27	0·06	
Potash, with trace of soda	..	..	..	0·64	0·11	
Sulphate of lime	..	..	..	0·26		
Sulphide of calcium	..	..	..	3·38		
				100·09		

Its formula approximates to $3Al^2O^3, SiO^3+3(3CaO,SiO^3)$. This formula was subsequently adopted by Rammelsberg for the natural mineral; and he arrived at it by a fresh analysis, quite independently of the observations of Professor W. H. Miller and myself on the artificial mineral. Natural Gehlenite is found in the Fassa valley, Tyrol, in opaque, grey, square prisms. It occurs imbedded in carbonate of lime in cracks in syenite.

Miscellaneous Analyses of Slags from Furnaces fed with Charcoal as Fuel, showing differences of composition.[5]

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
Silica	70·23	70·12	61·06	54·26	53·79	49·57	48·39	45·40	40·60	35 80
Alumina	6·37	6·25	5·38	6 76	13·04	9·00	6·66	18·20	9·80	4·20
Lime	20·41	19·71	19·81	24·56	25·67	..	..	27·40	11·90	2·14
Magnesia	..	0·70	7·12	0·28	0·57	15·15	10·22	2·40	2·40	4·06
Protoxide of iron	0·15	1·45	3·29	9·20	2·44	0·04	0·06	4·50	25·60	21·16
Protoxide of manganese	2·70	1·40	2·63	4·80	2·20	25·84	33·96	..	8·90	29·64
	99·86	99·63	99·29	99·86	97·71	99·60	99·29	97·90	99·20	97·00

I. By Klasek. From Rothau; from sphærosiderites (argillaceous ores); bluish white and enamel-like; grey iron.—II. By Karsten. From Peitz, Neumark; from bog iron ore; bluish white and glassy.—III. By Berthier. From Sjögren; from magnetic iron ore; bright green, enamel-like, and somewhat vesicular.—IV. By Klasek. From Rothau; from sphærosiderites; whitish grey to blackish, and pumice-like.—V. By Rammelsberg. From Rübeland; green and glassy; mottled iron. —VI. By Karsten. From Siegen; from spathic and brown iron ore; furnace working very hot; grey iron.—VII. By Karsten. From Siegen; furnace working well (bei Gaargang); the product spiegeleisen.—VIII. By Berthier. From Vienville; from pisolitic ore; olive-green, compact, vesicular, glassy, and transparent.—IX. By Mrazek. From Eisenerz, Styria; from spathic ore.—X. By Klasek. From Rothau; from sphærosiderite and red iron ore; dark greyish blue.

[5] I have selected these from Lindauer's tables.

Loss of Iron in the Blast-furnace Slag.

This is a point of much importance. In furnaces in this country fed with mineral fuel the loss may be estimated at about 2% on the average; and, generally, a sensibly larger loss indicates that the furnace is not in good working order. But at some iron-works in South Wales a loss far exceeding 2% is not only tolerated, but justified on the ground that, under the circumstances, a more complete reduction of the iron would be less profitable. Mr. Riley has expressed his opinion that, after having "carefully gone into this subject," the loss of iron in the slag has been estimated "far too high;"[6] and this he attributes to errors of analysis. I have no doubt that Mr. Riley is correct in his opinion with respect to the Dowlais Iron-works and most other British iron-works; but it is, nevertheless, certain that at some furnaces the iron allowed habitually to escape in the slag greatly exceeds 2%.

Mr. James, blast-furnace manager at the Blaina Iron-works, informed me that the slag from the furnaces under his direction contained on the average about 5% of iron, and that this statement was founded on the analyses of numerous samples of these slags by my friend Dr. Noad, a highly competent and trustworthy analyst. At the Ebbw Vale Iron-works (in 1859) it was admitted to me that the loss of iron in the slag was considerable, and in this case also the evidence was derived from Dr. Noad's results. Taking 5% as the loss, this would correspond to about 15 tons of Welsh mine, *i. e.* argillaceous iron-ore, for every 100 tons of slag. White iron was, of course, the quality of pig made. The reasons assigned to me in justification of the waste were, that the greater yield of the furnace and the less consumption of fuel more than compensated for the advantage to be derived from a more complete reduction of the iron. The pig-iron was needed for puddling, and if it were not sufficiently white the operation of puddling would require more time and labour and, consequently, more fuel and wages. By some ironmasters with whom I have discussed this matter of loss, it is regarded as a mistake to permit so much iron to escape unreduced, and they consider that it would be preferable to pay the puddlers a shilling a ton more for the extra labour in puddling iron less white than what they were accustomed to operate on.

From accurate yield-accounts of the furnaces it would not seem difficult fairly to balance the alleged pecuniary advantages of imperfect reduction of the ore against those of the opposite course. This, no doubt, has been done and action taken accordingly, yet more than one Welsh iron-master with whom I conversed on the subject expressed some misgivings as to the expediency of the waste, notwithstanding their toleration of it.

The following analyses of blast-furnace slags by Dr. Noad have been communicated to me by Mr. Levick, with permission to publish, and they have not a little surprised me.

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[6] Op. cit. p. 71.

	I.	II.
Silica	39·20	35·60
Alumina	15·20	15·80
Lime	35·50	33·10
Magnesia	2·84	4·20
Protoxide of iron	4·32	9·92
Alkalies, etc.	2·94	1·38
	100·00	100·00

No. I. was described as cream-coloured, and No. II. as dark green. They were easily and completely decomposable by cold dilute hydrochloric acid. Both are reported to have come from blast-furnaces in South Staffordshire, and No. II. from iron-works where a superior quality of iron was made. From my experience of the working of South Staffordshire blast-furnaces, and it is not inconsiderable, I should consider such slags as altogether exceptional, and as indicative of disordered furnaces. It will be remembered that I have described a slag of substantially the same composition, and containing about the same proportion of iron, from a South Staffordshire furnace; but it was dark grey, or greyish black rather, not cream-coloured, and it was produced when the furnace was working badly. No. II. slag surprises me still more with respect to the proportion of iron.

However much British iron-masters may deplore the loss of iron in their blast-furnace slags, they will, probably, derive some satisfaction from an inspection of several of the previously recorded analyses of slags from Continental blast furnaces, in which the loss immensely exceeds anything of the kind in this country. On the other hand, they will be somewhat puzzled to understand, that in two of the analyses in the table p. 503, Nos. VI. and VII., the loss is stated at about $\frac{1}{10}$%! I make no attempt to explain this, for, although the results are given on no less an authority than Karsten, yet the best men may occasionally err, and it is at least possible that this distinguished metallurgist may have done so in these instances. In both slags an enormous amount of manganese was present, from which the iron in the process of analysis may not have been completely separated.

Indications afforded by the Colour of Blast-Furnace Slags.

The blue colour which is so frequently observed in blast-furnaces in this country and elsewhere has been considered in the First Part of the Metallurgy (p. 27). It does not present any indication of much practical value, so far as I am aware.

The black colour of the slag deserves particular consideration. It is certain that slags which do not contain more than the usual amount of iron may be deep black and obsidian-like in mass, and the cause of the coloration in this case has not been satisfactorily explained. Sulphur, in the state of sulphide, there is reason to believe, may induce blackness in alkaline and earthy silicates,[7] but in what manner is unknown. The Dowlais slags, of which the analyses by Mr. Riley

[7] Vid. First Part of the Metallurgy, p. 29.

have been previously inserted, were for the most part black, and yet they did not contain more, on the average, than about 2½ % of protoxide of iron. Now many analyses of slags have also been presented of substantially the same composition as those of Dowlais, and containing as much iron and as much sulphide of calcium, and, nevertheless, they were not black. I am, therefore, unable at present to offer conclusive evidence that sulphur in the state of sulphide is a potent cause of black coloration, although I think it probable that such is the case. The fact is interesting, at least in a scientific point of view, and well deserves investigation.

The slag may appear black in mass and very deep green by transmitted light in thin slices, and this greenness is a sure sign of the presence of much protoxide of iron.

Leek-green coloration of the slag indicates the existence of much protoxide of manganese.

At the Ebbw Vale Iron-works I met with several lumps of blast-furnace slag, opaque, stone-like, and of a delicate pink colour, resembling that which appears in devitrified crown-glass, and which is ascribed to manganese. I was informed that this slag had been formed when the furnace charge contained much spathic ore.

Light grey slag generally accompanies the production of grey iron, at least when no inordinate amount of manganese is present in the furnace-charges.

Miscellaneous Observations on various points concerning Blast-Furnace Slags.

Spontaneous disintegration.—My friend Mr. Andreas Grill informed me (1859) that he observed a very curious slag flowing from a blast-furnace at the Park Gate Iron-works, Yorkshire. Very shortly after solidification it became completely disintegrated and reduced to fine powder. My colleague, Mr. Smyth, has recently brought me (May, 1863) a specimen of slag which spontaneously disintegrated in like manner during solidification. The slag was previously grey and cellular. The colour of the powder is light grey, and when breathed upon it evolves the odour of sulphuretted hydrogen. It has not yet been analysed. It was obtained from the newly erected furnaces at Workington, Cumberland, in which a mixture of "hard" and "soft" red hæmatite was smelted, with the production of grey iron. In the First Part of the Metallurgy (p. 40) experiments by Sefström are recorded, in which exactly the same phenomenon was observed in the case of certain highly basic silicates of lime, and it is probable that it is due to excess of lime in the furnace-slags above mentioned. A similar phenomenon also takes place during the solidification of the fused double sulphate of potash and protoxide of copper ($KO, SO^3 + CuO, SO^3$).* It was long ago announced by Berzelius, and I have repeated the experiment, which is well adapted for lecture illustration.

Magnesia.—This substance tends to induce infusibility, and in large

* Berzelius, Traité de Chimie, 2de éd. Française, 1847, 4. p. 163.

proportion is, on that account, injurious. But in furnace-charges in this country magnesia is present in proportion too small to occasion any sensible effect. The use of dolomite (carbonate of lime and magnesia) as a flux instead of limestone should obviously be avoided.

Manganese.—Protoxide of manganese readily combines with silica, and therefore greatly tends to corrode the lining of the furnace. It induces liquidity in the slag. In some of the analyses of slags from Continental blast-furnaces previously inserted the proportion of protoxide of manganese is very large. The corrective clearly is silica, for, until the oxide is completely saturated with silica, it is obvious that it must continue to exert its corrosive action, to the great damage of the lining of the furnace.

Titanic acid.—I know nothing from my own experience of the effect of this acid on blast-furnace slags on the large scale, but I am assured by Swedish metallurgists, skilled in the smelting of iron in Sweden, that it, like magnesia, renders the slag difficultly fusible, and may be the cause of much trouble in consequence.

Potash.—In studying the composition of blast-furnace slags the chemist must be struck with the comparatively large proportion of potash which they contain. The value of the potash, when present to the extent of 2% in a slag, may be roughly estimated at 1*l.* per ton of slag. It is much to be regretted that such an enormous amount of this alkali should be annually wasted in our slags, and the question of the possibility of its economical extraction merits more attention than it hitherto appears to have received. In the case of the spontaneously disintegrating slags it would be worth while to try in what degree it might be dissolved out by water; for if these slags be, as is reasonably supposed, highly calciferous, their composition, as every analytical chemist knows, must be favourable to its separation by this solvent. Moreover, it is easy to obtain any ordinary blast-furnace slag in the state of easily crumbling pumice by allowing it, not to flow into, but to simply come in contact with, water. It is extraordinary how voluminous, light, and vesicular a mass is thus procured.

Miscellaneous and Accidental Products of Blast-Furnaces.

Silica.—Professor H. Rose, of Berlin, has published the following interesting account of the production of fibrous silica in a blast-furnace in Rübeland, in the Harz.[9] He received specimens of it from Professor Wöhler. It consisted of perfectly white silky fibres in concentric layers, and contained here and there black specks of iron and graphite, with a few extraordinarily small yellow-red cubes of cyano-nitride of titanium. The silica was carefully separated, but it was not possible to free it completely from the black specks. Its specific gravity was 2·32, which is a little too high, on account of the presence of iron. When left in a damp situation it became in places pale yellowish

[9] Ueber die Kieselsäure der Hohöfen. Ann. d. Phys. u. Chem. Poggend. 1859, 108, p. 651.

from the rusting of the iron. Heated with carbonate of soda it evolved ammonia, which was collected and weighed as platino-chloride of ammonium. It yielded 0·07% of nitrogen. This result is a little too low, as the glass tube cracked during the analysis, and the nitrogen may be estimated at 0·10%. Another portion was treated with hydrochloric acid, in order to dissolve the iron, and evaporated with hydrofluoric acid, when a minute quantity of matter remained. This was moistened with sulphuric acid, and the greater part of the excess of acid was driven off by evaporation. When cold the residue was treated with water at the ordinary temperature. The solution thus obtained became turbid on boiling, and deposited 0·004 gramme of titanic acid (TiO^2). The filtrate gave no residue by evaporation. The portion left undissolved by water contained graphite and extraordinarily small yellow cubes of the titanium compound. It was not ascertained whether the ammonia was evolved from the silica, from nitride of silicon, or from the intermixed titanium compound, which first became visible after the solution of the silica in hydrofluoric acid: the latter source is the most probable.

According to Leonhard the occurrence of fibrous silica is by no means rare in hearth-bottoms, in cavities in the walls of the hearth, and in the "bears" of iron-smelting blast-furnaces. He describes it as in the form of snow-white, silky, radiating tufts, consisting of hair-like crystals, so light that the least movement of the air suffices to blow them away.[1] Vauquelin appears to have first discovered their true nature. Gurlt also announces that artificial quartz has long been known, and is usually found in the vicinity of the twyers, in cracks or cavities of the hearth-stones, together with graphite and the titanium compound.[2] Of the various localities where it has been observed he mentions Plons, near Sargans, and numerous iron-smelting blast-furnaces in the Harz and Westphalia. Uncrystallized compact silica, he further states, has been found accompanying the crystallized variety in blast-furnaces, partly as a finely granular, translucent, compact mass, and often in shot-like or botryoidal forms, and partly earthy, of greater or less coherence. In the fibrous state it is known as iron-amianthus, and a specimen of this variety from the Olsberg furnaces, according to the analysis of Schnabel, had the following composition:—

Silica	98·13
Alumina	1·24
Lime	0·46
Magnesia	traces
Protoxide of iron	traces
	99·83

Its specific gravity was 2·59. It was insoluble in acids, and before the blowpipe, with the addition of carbonate of soda or charcoal, melted, with effervescence, into a transparent glass.

Fibrous silica in the blast-furnace probably owes its origin to the oxidation of silicon, which is certainly separated in a greater or less

[1] Hütten-Erzeugnisse, p. 205. [2] Übersicht der pyrogenneten Mineralien, p. 40.

degree under the same conditions as graphite. According to Deville it is oxidized at a high temperature, even by carbonic oxide. If it be a product of the oxidation of silicon in any way, it occurs just where it might be expected, namely, where silicon is known to exist.

I have received from Mr. E. Riley, what he designates as a sort of skin occasionally found on the surface of the pig-iron, and which, he states, consists chiefly of silica.

Jeffreys has recorded a remarkable instance of the supposed volatility of silica at high temperatures through the agency of the vapour of water.[3] He allowed a large quantity of steam to pass through a potter's kiln, of which the temperature more than sufficed to melt pig-iron, and he afterwards observed round the opening of the kiln, from which the steam escaped, several pounds of silica deposited in the form of snow. In commenting upon this statement Berzelius adduces, as a parallel case, the well-known volatility of boracic acid in the vapour of water, and the fact observed by Gaudin concerning the volatilization of silica when melted before the oxyhydrogen blowpipe.

The preceding account is, as the reference shows, taken from the report of Berzelius. The observer is Mr. Julius Jeffreys, of the late "Honourable East India Company's Medical Establishment," who communicated a paper on the subject to the Royal Society, and of which an abstract, in a few lines, was published in the 'Proceedings.'[4] Another paper on the same subject was communicated by the author to the British Association in the same year, and a somewhat detailed description of it will be found in the report of the Proceedings of that year.[5] I have read this description with the greatest attention, and anything more wanting in scientific precision, and, therefore, less satisfactory, can hardly be conceived. No analysis of the silica alleged to have been deposited is stated to have been made, and there is not, indeed, any proof that this deposit was silica at all, much less that vaporization of silica under the circumstances recorded had actually taken place. The observations were made at Furrukabad, 800 miles north of Calcutta. The evidence, which appears to have satisfied Mr. Jeffreys, I confess does not convince me. I have introduced this notice to serve as a warning against the too hasty acceptance of announcements of startling scientific novelties, and as an illustration of the importance of consulting original papers themselves, instead of trusting to abstracted notices, however honestly compiled.

Supposed Garnet.—I received from Mr. Russell, a mineral collector, a portion of a "bear," which he himself procured at one of the Monkland blast-furnaces in Scotland; and I observed in it a few small beautiful crystals resembling garnet. I submitted them to Professor W. H. Miller for examination, of the results of which he has published a notice.[6] There was not sufficient material for chemical analysis, even by operating upon the whole. The crystals had the appearance of dark-

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[3] Berzelius, Jahres-Bericht, 1843. p. 90.

[4] Proceedings of the Royal Society, 1840, p. 232.

[5] Brit. Assoc. Report. 1840, p. 125.

[6] Phil. Mag. Oct. 1858.

coloured garnet. One, nearly [illegible] in diameter, having very bright and perfect faces, was measured with the reflective goniometer: it had the form of the rhombic dodecahedron, with the edges replaced by bevelled planes, which is that of a not uncommon variety of garnet.

I have not met with garnet as a blast-furnace product in any other instance. On the authority of Studer, it is asserted by Gurlt, that garnet has been found in blast-furnace slags; but no details as to locality, etc., are given.[7] Leonhard states that garnet has either never, or only been very seldom, observed in blast-furnace slags.[8]

Furnace cadmia or calamine (Gichtschwamm, Ger.).—In smelting zinciferous iron-ores, a compact incrustation of furnace cadmia, consisting chiefly of oxide of zinc, is apt to form round the throat of the furnace. In some instances this deposit accumulates to such an extent that it requires to be detached from time to time. I have seen numerous specimens of it from British as well as from Continental blast-furnaces. It has generally a dark greenish grey colour, and a more or less stratified structure. A specimen, which my colleague, Mr. Smyth, recently obtained at the Seend furnaces in Wiltshire, where iron-ore from the Greensand formation is smelted, is beautifully crystallized. The crystals are distinct, bright, dark green, translucent or transparent, hexagonal prisms.[9] On superficial examination they were at first mistaken for epidote. At the Stanhope furnaces, in Durham, I observed a considerable deposit of greyish white oxide of zinc on the lower part of the tunnel-head, and a bright luminous flame proceeding from the mouth.

Ebelmen has given the following analysis of furnace-cadmia from an iron-smelting blast-furnace at Treveray, Meuse, in France; it was formed of concentric zones, of a more or less deep-grey colour, and contained here and there shots of metallic lead; its specific gravity was 4·97 at 15° C.; by the action of hydrochloric acid, a little sulphuretted hydrogen was evolved, and a small quantity of insoluble matter was left, consisting of sandy particles and metallic lead.[1]

Oxide of zinc	91·6
Protoxide of iron	3·0
Protoxide of lead	1·6
Sulphide of lead	1·6
Lead	1·4
Silica and sand	0·8
	100·0

Specimens of furnace-cadmia were exhibited in the Zollverein department of the International Exhibition, in 1862, from the Concordia Mining and Smelting Company's iron-smelting blast-furnaces, Ichenberg, near Eschweiler, Aix-la-Chapelle. Nearly 2000 ctrs., or about 100 tons, of this cadmia (Gichtschwamm) are annually obtained at these furnaces.

Cyano-nitride of titanium.—This interesting and remarkable compound,

[7] Übersicht der pyrogenneten kunstlichen Mineralien. Freiberg, 1857, p. 61. A reference is given to Studer's Lehrbuch d. physikal. Geographie u. Geologie, p. 121.

[8] Hütten-Erzeugnisse, p. 327.

[9] Vid. First Part of the Metallurgy, p. 540.

[1] Trav. Scient. 1. p. 304.

first examined by Wollaston in 1822, and now so frequently found in our blast-furnace "bears," has been previously described. I have numerous very beautiful specimens of it from furnaces in South Wales, South Staffordshire, and Scotland. A specimen analysed by Wöhler had the following composition:—

Titanium	77·26
Nitrogen	18·30
Carbon	3·64
Graphite	0·92
	100·12

This leads to the formula $TiCy+3Ti^3N$.

The largest crystals I have ever seen were obtained from a furnace in South Wales, and are now in the metallurgical collection of the Royal School of Mines. I have one specimen coated with a grey metallic tarnish. In another specimen the minute cubes are piled up into the form of the regular octahedron, exactly as sometimes occurs in octahedrons of fluorspar.

Graphite or kish.—Comparatively large quantities of graphite in thin plates escape from the blast-furnace during tapping, and appear on the surface of the metal. I have obtained fine specimens of it from many furnaces; but some of the finest have come from the furnaces at the Dowlais Iron-works and at the Clarence Iron-works, near Middlesboro'-on-Tees, belonging to my friend Mr. I. Lowthian Bell. I have carefully examined that from the first-named locality, and have found unmistakable evidence, I think, of the presence of silicon in it.

Colour of the flame.—In the furnaces of South Wales I have generally observed that the flame issuing from under the tymp is bright yellow. At the Ystalyfera furnaces, especially, in which anthracite is used as the fuel, and from which a considerable amount of flame is always allowed to escape at the fore-part, I have been much struck with the pure mono-chromatic character of this flame. While enjoying on one occasion the hospitality of the proprietor, Mr. J. Palmer Budd, a party of us, including ladies, one of whom wore a *red* shawl, visited the furnaces at night; when, so intensely yellow was the flame, that not the slightest tinge of red was visible in the shawl. The light evolved was precisely similar in this respect to that produced by the combustion of alcohol containing chloride of sodium in solution. When a stick of bright red sealing-wax is placed on brown paper and viewed by this flame, it cannot be distinguished in colour from the paper. The colour of the flame from the furnaces above mentioned, there can be little doubt, is due to the presence of soda existing as chloride of sodium in the coal. There is reason to believe that soda is present in coal more frequently,—if not generally,—and to a greater extent than is supposed. Not long ago I had occasion to put down a small steam-engine at the bottom of a Thick-coal colliery at West Bromwich, in South Staffordshire, in order to raise water which had accumulated in old hollows in a deep part of the mine. The boiler was supplied with this water; and, not suspecting anything unusual, it was not cleaned out more frequently than customary. It exploded, happily

without causing any serious harm; and a thick saline incrustation was found at the bottom. This was analysed, and proved to contain more than 95% of chloride of sodium.

ON THE CONNEXION BETWEEN THE PRESENCE OF MANGANESE AND SULPHUR IN SLAGS.

Mr. Parry informs me that the slag produced in smelting spathic ores at the Ebbw Vale Iron-works has contained as much as 8% of protoxide of manganese, and not less than 2% of sulphur. Its colour was green. Mr. Parry further states that he has always found that when there is much manganese in the slag, it is accompanied with a considerable quantity of sulphur. This conclusion has been fully confirmed by the analyses of Dr. Noad. When other ores not rich in manganese were smelted with the same fuel as those above mentioned, the slag contained less sulphur, and the pig-iron a proportionately larger quantity. This is a point of considerable practical importance; and it may possibly tend to explain the formation of *helvin*, or tetrahedral garnet, of which the composition is given in the First Part of the Metallurgy, p. 344. This remarkable mineral is essentially a silicate of protoxide of manganese and glucina, but contains nearly 6% of sulphur in the state of sulphide.

ON THE REDUCTION OF PHOSPHORIC ACID IN THE BLAST-FURNACE, AND THE PASSAGE OF THE PHOSPHORUS INTO THE PIG-IRON.

Berthier long ago announced the fact that slags accompanying the production of pig-iron containing phosphorus were free from that element. He investigated the question synthetically as well as analytically; and the original paper, in which his results are recorded, is worthy of careful study.[2] As far as I have yet observed, the *ordinary* slags from English blast-furnaces do not contain a sensible quantity of phosphoric acid; but I have not examined any which have been derived from ores containing an unusual amount of that acid, such, for example, as some varieties of the Northamptonshire ore. My experience in this respect is confirmed by the observations of Price and Nicholson, and of Mr. E. Riley. The presence of phosphoric acid in sensible degree in blast-furnace slag is exceptional, and appears to be connected with imperfect reduction of the iron. By way of illustration, the following analyses are presented:—

	I.	II.	III.	IV.	V.	VI.
Silica	42·06	41·11	37·84	40·04	34·96	45·31
Alumina	13·05	13·45	13·20	12·69	16·66	10·76
Lime	32·53	29·82	20·68	32·36	29·48	30·70
Magnesia	1·06	4·75	2·93	1·65	5·36	2·57
Protoxide of iron	4·94	6·44	20·83	7·81	6·83	2·29
Protoxide of manganese	2·26	0·66	0·80	1·12	0·99	3·07
Alkalies	2·69	1·84	1·08	1·28	1·83	0·34
Phosphoric acid	0·19	0·15	1·77	1·08	2·63	3·51
Sulphide of calcium	1·03	1·34	0·87	1·38	1·45	2·05
	99·81	99·56	100·00	99·41	100·19	100·60

[2] Sur les fontes phosphorées, etc. Par M. P. Berthier. Ann. d. Mines, 1838, 3 s. 14. p. 113.

I. This slag came from the blast-furnace named La Providence, at Marchienne, Charleroi, Belgium. The analysis has been previously inserted.—II. and III. These analyses were made by Price and Nicholson. White iron was being made, doubtless with Welsh coal and hot-blast, although this is not specially stated. The slag in No. II. resembled black bottle-glass in appearance, and, from its liquidity in a molten state, was what is termed a "scouring cinder;" it was derived from argillaceous ore. In No. III. the slag was exceedingly heavy, of a pitch-black colour, with the surface of the blocks in the *tap-waggons*, *i.e.* cinder-tubs, of the dull, dark red, bronze-like aspect characteristic of very bad furnace slags.—IV. and V. These analyses were made by Mr. E. Riley at the Dowlais Iron-works. Potash was the only alkali found. No. IV. was from No. 9 furnace, hot-blast, and working on equal weights of Northamptonshire ore and refinery cinder. It was a dark green scouring cinder. No. V. was from No. 3 furnace, hot-blast, and working also on precisely the same charges of ore and cinder as No. IV. It was a black scouring cinder.—VI. This analysis was made by Hess, in Liebig's laboratory. The slag was black and obsidian-like, and on that account was selected for analysis by Leonhard in illustration of the artificial production of that mineral.[a] It was from a blast-furnace at Friedrichsthal, near Freudenstadt, Wurtemberg, and was derived from the smelting of pisolitic and brown iron ore, with limestone as flux and charcoal as fuel. In the original the analysis is not exactly as I have tabulated it. The sulphur was 0·91, and set down separate, whereas I have computed it as sulphide of calcium. There is also 0·52% of phosphate of lime put down as a distinct item, and this I have included in the total lime, not deducting the phosphoric acid.

In the table of analyses by Mr. E. Riley, of Dowlais blast-furnace slag, p. 499, it will be observed that there is a direct relation between the proportions of iron and phosphoric acid in the slag.

The preceding results establish the fact, *cæteris paribus*, of the connection between the presence of iron and that of phosphoric acid in the slag; and this conclusion is abundantly confirmed from analyses of slags comparatively free from iron. It is, moreover, precisely what might have been anticipated; for, obviously, the condition tending to the imperfect reduction of the iron will likewise tend to the imperfect reduction of the phosphoric acid. And this condition is especially apt to occur when white iron is produced; because the proportion of fuel is smaller and the temperature of the furnace lower than when grey iron is made.

Further; the conclusion above stated agrees perfectly with what has previously been advanced concerning the reduction of lake and bog iron ores in Finland in the Stückofen and high blast-furnace, respectively. In the former, as an enormous proportion of iron is left

[a] Hütten-Erzeugnisse u. andere auf künstlichem Wege gebildete Mineralien als Stutzpuncte geologischer Hypothesen, von K. C. v. Leonhard. Stuttgart, 1858, p. 175.

unreduced in the slag, iron comparatively free from phosphorus is obtained; whilst in the latter, pig-iron containing a sensible amount of phosphorus, and, therefore, well suited for fine castings not requiring any great strength, is always produced.

In No. VI. analysis it will be observed that whilst the proportion of iron is much less, that of the phosphoric acid and manganese is considerably greater, than in the other analyses. It is probable that manganese would, like iron, tend to retain phosphoric acid in the slag; and it is desirable that observation should be directed to this point, which may prove to be one of practical importance.

According to Price and Nicholson when ores containing from 2% to 3%, and slags (such as the tap-cinder of the puddling furnace) from 8% to 10% of phosphoric acid are smelted with hot-blast, all the phosphoric acid is reduced, and the phosphorus passes into the pig-iron; but they had had no opportunity of ascertaining whether the same result would occur with cold-blast.

Grey pig-iron smelted with hot-blast from pisolitic iron ore, and from a mixture of tap-cinder and shale, respectively, contained 2·56% and 6·94% of phosphorus. The slags accompanying these two pig-irons were composed as follows:—

Silica	45·64	41·11
Alumina	10·84	9·46
Lime	35·01	37·90
Magnesia	3·16	2·11
Protoxide of iron	0·71	0·39
Protoxide of manganese	trace	1·61
Sulphide of calcium	3·30	6·41
Alkalies	0·82	0·71
Phosphoric acid	trace	trace
	99·48	99·70
Pig-iron, contained of phosphorus	2·56	6·94

Mr. F. C. Wrightson, in a paper which he read to the Chemical Section of the British Association in Birmingham, 1849, asserted that, *cæteris paribus*, pig-iron smelted with hot-blast contains more phosphorus than pig-iron smelted with cold-blast; and he adduced in evidence the following series of results from his own analyses of specimens of pig-iron made with cold and hot blast from South Staffordshire ores, chiefly west of Dudley.[4]

	Phosphorus per cent.						
Cold-blast pig-iron ...	0·47	0·41	0·31	0·20	0·21	0·03	0·36
Hot-blast pig-iron ...	0·51	0·55	0·50	0·71	0·54	0·07	0·40
Difference	0·04	0·14	0·19	0·51	0·33	0·04	0·04

These differences, it must be admitted, are not very startling, the greatest being 0·51%. In three of the determinations it is only 0·04%; but some allowance must be made for necessary errors of analysis, as every experienced analyst well knows that, in the case of phosphorus, it is not easy to obtain results in two analyses of the same

[4] The paper will be found *in extenso*, Chem. Gaz. 7. p. 478, 1849.

sample approximating so closely as 0·04%; especially when the matter operated on contains only a very small proportion of phosphorus, as was the case with the pig-irons which Mr. Wrightson analysed.

Price and Nicholson, with a view to test the correctness of the preceding assertion of Mr. Wrightson, determined the proportions of phosphorus in pig-iron smelted from argillaceous ores, at the Aberdare Works, with cold-blast, and with hot-blast at the temperature of 600° F. Their results are as under:—

	Phosphorus per cent.			
	I.	II.	III.	IV.
Cold-blast pig-iron	0·81	0·62	0·68	0·63
	V.	VI.	VII.	VIII.
Hot-blast pig-iron	0·74	0·68	0·71	0·58
Difference	0·07	−0·06	−0·03	0·05

In both cases the metal was what is known as good No. 2 foundry iron. In two instances the phosphorus is higher in the cold-blast pig-iron, and in two it is lower; and in no instance is the difference so great as not to be readily explained, either by corresponding variations in the proportion of phosphoric acid in the ores, or by errors of analysis. The slags accompanying the production of Nos. I., II., V., VI. were analysed, and the results are given below:—

	I.	II.	V.	VI.
Silica	39·95	40·20	41·64	42·94
Alumina	17·41	16·45	13·20	16·29
Lime	29·64	30·00	35·91	31·10
Magnesia	6·47	7·29	4·21	4·16
Protoxide of iron	0·24	0·57	0·11	0·34
Protoxide of manganese	0·91	0·84	0·74	0·51
Sulphide of calcium	3·60	2·71	2·19	2·16
Alkalies	1·46	1·30	1·70	1·87
Phosphoric acid	trace	trace	trace	trace
	99·68	99·36	99·70	99·37

It was only by the aid of the molybdate of ammonia test that the minute traces of phosphoric acid present could be detected.

The foregoing results lead to the conclusion that, under ordinary conditions and when the furnaces are in good working order, reduction of the phosphoric acid takes place as completely with cold as with hot blast, or, what is equivalent, the temperature of a cold-blast furnace suffices to effect what may be practically regarded as perfect reduction of the phosphoric acid existing in the charge; a conclusion opposed to that at which Mr. Wrightson had previously arrived.

Leonhard has published an analysis of a slag extraordinarily rich in phosphoric acid, made by Hess in Liebig's laboratory.[5] It was what he designates "furnace pumice,"[6] and came from the Concordia Iron-works, Coblenz. It was produced in smelting pisolitic and brown

[5] Op. cit. p. 175.

[6] Ofen-Bimsstein, or Gaarschaum.

iron ore with charcoal and Muschelkalk limestone as the flux. I presume that it acquired its structure from having come in contact, in a molten state, with water. I have seen beautiful specimens of pumice made at the blast-furnace in this manner. A black slag when carefully brought in contact with water will swell up surprisingly into a voluminous, excessively light, white, cellular mass. The composition of the slag was as follows:—

Silica	27·48
Alumina	25·78
Lime	25·47
Magnesia	0·41
Protoxide of iron	0·91
Protoxide of manganese	3·59
Phosphoric acid	9·66
Titanic acid	6·70
	100·00

This slag, I should suppose, must have been refractory from the presence of so large an amount of alumina. I am not aware whether any trustworthy experiments have yet been made to ascertain what the effect of alumina may be in preventing the reduction of phosphoric acid. Should it be found beneficial, a mineral containing a large proportion of alumina occurs at Belfast; and it has recently been proposed to employ it as a flux in the smelting of siliceous iron ores with a view to prevent the reduction of the silica and the passage of the silicon into the pig-iron. It is conglomerate in structure. Messrs. Richie and Sons, manufacturing chemists of Belfast, are, I am informed, prepared to supply it at a moderate cost.[7] An analysis of this mineral, which is known as "aluminous ore," will be found in Table III., No. 9.[8]

Economical Application of Blast-furnace Slags.

Blast-furnace slag, as every one who has travelled in iron-producing districts must have observed, is extensively used for building purposes, especially walls; and it would not be easy to find more durable material. A few years ago a paper was read to the Society of Arts by Dr. William H. Smith, of Philadelphia, U.S., on "the utilization of the molten mineral products of smelting furnaces." The author stated, that his system of utilization had "been for years before the public," and had been "described in several lengthy specifications:" so that he appears to have obtained the protection of several patents

[7] A pamphlet has been published on this mineral with the following title:—Observations upon a New Mineral and its Adaptation for the Improvement of Siliceous Iron Ore. Belfast, 1862, p. 8.

[8] Since the foregoing observations were in type, Caron has communicated to the French Academy a paper on the elimination of phosphorus from pig-iron. He seems not to have been acquainted with what had been previously done with respect to the reduction of phosphates in the blast-furnace, and the concentration of the phosphorus in the pig-iron. Thus he states, "Having several times treated ores completely free from phosphorus with the addition of wood charcoal, phosphate of lime, and silica, I have constantly found in the cast-iron produced nearly all the phosphorus which I had put into the crucible in the state of phosphate." He found also that without the presence of silica the same result occurred in a brasqued crucible.

in carrying out his system. Slag was to be applied to "a thousand uses;" it was to be manufactured into bricks and ornate architectural mouldings; it was capable of being "cast into as great a variety of forms, solid and hollow, as iron itself, with the superior advantage of being susceptible of the admixture and blendings of colour, so as to render it equal in brilliancy to agate, jasper, malachite, the variegated marbles, and other more valuable varieties of the mineral kingdom;" by proper annealing, it may "be made to acquire a surface, or texture, at least ten times as durable as that of marble, and is susceptible of a polish equal to agate or cornelian."

The author concludes his paper with an elaborate statement of the cost of the manufacture of slag tiles and slabs, from which I select the following items:—

	£.	s.	d.
Commercial value of 100 tons, 1 in. thick, gross	590	12	6
Less cost	126	5	0
	£464	7	6
Value of annual product at 500 tons per day	£696,562	10	0
Commercial value of 100 tons, 1½ in. thick, gross......	£393	15	0
Less cost	126	10	0
	£267	5	0
Value of annual product at 500 tons per day	£400,875	0	0

It was computed that the iron-smelting works of Great Britain alone annually yielded from 6 to 10 million tons of slag. The author, apparently not satisfied with this source of supply, refers to the slags produced in the smelting of copper and lead, "without considering zinc and other metalliferous sources." Slags from zinc furnaces would, I should imagine, be somewhat novel. Amongst "other essential elements of success," one consists "in the protection of the molten and hot material from the sectional polarization of its heat, or thermal electricity." This passage of high-sounding scientific phraseology may have been intelligible to the audience at the Adelphi; but it is far beyond my comprehension.

The author asserted, that this slag "field of scientific research and industrial enterprise" was novel; and he seems to have claimed for himself the entire merit of originality in the application proposed. How far this claim is correct will be seen in the following extract from the specification of a patent granted to a Mr. John Payne, Nov. 21st, 1728.[9] "Lastly is described the method of moulding or shaping the scoria or dross of divers mettalls and ores by fusing or melting, as before specified, with such mixtures as will in a great measure prevent its being brittle, and also gives it divers colours, so as to make it the more ornamentall and usefull where other ponderous

[9] No. 505. Abridgments of Specifications relating to the Manufacture of Iron, p. 4.

and vitrified matter is wanting, which scoria or dross, when prepared, is to be placed in moulds and pressed down by a screw or weight so as to fill the moulds to the proper shape designed for it."

Notwithstanding the glowing prospect of profit set before the British public by Dr. Smith, our capitalists have not been attracted, and iron-masters still continue to dissipate the valuable treasure which they possess in their blast-furnace cinders. One of two things is certain,—either Dr. Smith must have been very sanguine, or the British public very stupid.

Messrs. Chance, of the Spon Lane Glass-works, near Birmingham, obtained a patent in 1855 "for improvements in casting articles of the slags produced by the smelting of iron and other ores."[1] The slag, melted at a high temperature, was run into sand-moulds previously heated. They also endeavoured to utilize the trap-rock of the neighbouring Rowley Hills for building purposes and architectural ornaments. It was melted, then moulded by pressure, and subsequently devitrified by slow cooling, or, what is equivalent, by long annealing. In some houses at West Bromwich may be seen ornamental lintels produced in this manner. The process, however, did not answer commercially, and was abandoned.

Effects of long-continued Heat upon Sandstone in the Hearth-bottom.

When grit or coarse sandstone is used in the hearth-bottom of blast-furnaces, it occasionally acquires a columnar structure, exactly like basaltic columns in miniature. I have several beautiful examples of this alteration.

Mr. S. H. Blackwell has presented me with singularly changed pieces of sandstone from the hearth-bottom of one of his blast-furnaces. They are metamorphosed to such a degree, that when seen by the side of a piece of the original stone, no one would suppose that they had been derived from the latter. They appear as though they had undergone incipient vitrification, being glazed slightly on the surface. They are impregnated throughout with bright minute particles of metallic iron, and one piece is traversed by a vein of iron. I am inclined to believe that the change of structure must be due to the action of alkaline vapour; but I am somewhat puzzled to account for the dissemination of iron in minute, and apparently isolated, particles through the mass.

On the Substitution of Lime for Limestone as a Flux.

At Ekaterinenburg, in the Ural, experiments were made many years ago on the comparative advantages of lime and limestone as fluxes.[2] It is recorded that after the use of lime during 13 days, nothing peculiar was observed in the working of the furnace. Pig-iron of good quality was obtained, suitable for munitions,[3] hard-ware, and

[1] A.D. 1855, September 3. No. 1985.

[2] Annuaire du Journal des Mines de Russie. Année 1836. S. Pétersbourg. Imprimé à Paris, 1840.

[3] I use the same word as in the original French; for I do not know whether cannon or shot, or both, were intended.

other objects; and by the substitution of lime for limestone there was an economy of 43 copecs for every 100 pouds of ores smelted, *i. e.* 1*s.* 3*d.* for about 13 cwts. (of 112 lbs. to the cwt.).

The following notice has been published of the results of similar trials at the iron-works of Ougrée, near Liége, in Belgium.[4] When limestone was used, for 100 kil. of pig-iron, the average consumption of coke during 6 lunar months was 160½ kil., whereas, by the use of lime during the same period, it was reduced to 146¼ kil., thus showing a saving of 8% of coke. The average make of pig-iron with limestone during 28 days was 461,000 kil., *i. e.*, about 115 tons (of 2240 lbs. to the ton) per week; and with lime during the same period, it was 735,000 kil., *i. e.*, about 183 tons, which represents an increase of make to the extent of 24·3%. Corresponding results were obtained with another furnace, worked during 3 months with limestone, and during other 3 months with lime; and the average consumption of coke per 100 kil. of pig-iron was 162 kil. and 147¼ kil. respectively. In the former case the average production of pig-iron per lunar month was 469,000 kil., *i. e.*, about 117 tons per week, and, in the latter case, it was 563,000 kil., *i. e.*, about 141 tons per week. When the preceding notice appeared, the furnaces at Ougrée had been working with lime during 3½ years, with the same successful results. The saving per year, notwithstanding the cost of burning the lime, was estimated at 30,000 francs, *i. e.* about 1200*l.* In consequence of the announcement of these results, similar experiments were conducted by Eck in 1852, at the Royal Smelting-works, in Upper Silesia.[5] During 10 consecutive weeks, in two furnaces working with limestone as the flux, the consumption of coke per 100 lbs. of grey pig-iron (of a "coarsely granular and bright fracture, such as that used for puddling") was 228 lbs. and 227¼ lbs. respectively; and in the same furnaces working with lime during other 10 consecutive weeks, the consumption per 100 lbs. of pig-iron was 223 lbs. and 218¼ lbs. respectively. The increase of make by the use of lime was 3·3% and 2·4% respectively. Taking the average result of both furnaces, the saving in coke was 3·1%, and the increase of yield 2·85%. In one of the furnaces limestone was tried from January to the middle of February inclusive, and in May; and lime from the middle of February to the end of April. In the other furnace limestone was tried from the middle of February to the end of April inclusive; and lime from January to the middle of February inclusive, and in May. The experiments were thus comparative with respect to the influence of the seasons.

Mr. Menelaus informed me (Aug. 11th, 1863) that there was only one furnace at Dowlais working on lime, and expressed his conviction that the use of lime lessens the consumption of coal and softens the iron. He further stated that they were so satisfied as to its economy, that they proposed, as soon as convenient, to replace limestone by lime in all the furnaces.

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[4] Edinburgh New Philosophical Journal, April, 1854, p. 378. Quoted from the Zeitschr. d. Östr. Ing. Vereins. 1852, p. 145.

[5] Karsten's Archiv. 2 s. 25, p. 436. 1853.

On applying to Mr. Parry for information concerning the use of lime at the furnaces of the Ebbw Vale Iron Company, I received the following reply (Aug. [illegible]):—"We have had lime off and on for some years past, as managers have been changed. A few years ago I found the furnace worked better and carried more burden with lime than limestone. There was a saving of expensive fuel in the furnace to the full amount of inferior fuel used in calcining the lime. On the whole, I consider the use of caustic lime an advantage. At the Sirhowy Iron-works (belonging to the Ebbw Vale Company), lime has been used for years, the same manager being there who approves of it, and it is only two months ago that our head men have been ordered the renewal of its use at both the Ebbw Vale and Victoria Works, so that I may say the whole establishment is now using caustic lime." When I visited the Cyfarthfa Works in 1859 lime was used in the hot-blast, and limestone in the cold-blast furnaces.

On the Use of Blast-furnace Slag as a Substitute for Limestone.

At the Blaina Iron-works some years ago the supply of limestone was suddenly cut off on account of a dispute with the owner of quarries from which it had always before been obtained. There was no other source from which it could be economically procured, and it was determined to try blast-furnace slag as a substitute. Mr. Levick assures me that it answered perfectly, and that he used the same slag two or three times over without inconvenience. The circumstances in which such a course might be adopted must, I should suppose, be very restricted.

Application of Chloride of Sodium.

In 1851 a patent was granted to Mr. Frederick Crace Calvert, of Manchester, for "Improvements in manufacturing iron, and in manufacturing and purifying coke."* I have referred to this patent when treating of coke in the First Part. The claim is for the use of chlorine or hydrochloric acid, chlorides or hypochlorites in smelting iron, either by introducing chlorine into the blast-furnace, or bringing it or hydrochloric acid in contact with the ores when being roasted. Chloride of sodium is preferred, though any cheap chloride or hypochlorite will answer. It is recommended to employ 6 parts by weight of chloride of sodium to 200 parts of the other materials of the charge. The effect of this addition, Mr. Calvert alleges, is to remove to a great extent the phosphorus and the sulphur with which the sodium unites to form a slag.

The process with common salt has been well tried on the large scale at the Ebbw Vale Iron-works under Mr. Calvert's own direction; and the information which I have received on the subject from the works is that no advantage resulted from the nostrum in question. The same process has also been tested by Mr. Levick; and Mr. James, his blast-furnace manager, informs me that he thought the result was beneficial rather than otherwise, which is not saying much. Mr. James con-

* A.D. 1851, Oct. 30. No. 13,793. Abridgments of Specifications relating to the Manufacture of Iron and Steel, p. 111.

trived an ingenious apparatus for injecting the salt into the furnace through the back twyer, and he showed me an actual experiment with it at one of the Coalbrook Vale furnaces, belonging to Mr. Levick. The flame at the mouth seemed to increase decidedly in yellowness. A more effective method of trying the process cannot, I should think, be imagined. I am not aware whether Mr. Calvert has succeeded in introducing his process into any iron-works of importance. Ironmasters and blast-furnace managers have rather a wholesome dread of blast-furnace doctors, especially those who administer nostrums to remove phosphorus and sulphur.

Explosions in Blast-furnaces.

During the last few years several explosions have occurred in various blast-furnaces in this country, and have for the most part been duly chronicled in the newspapers. I have collected the following records of such accidents:—

Mr. S. H. Blackwell informed me that about the year 1857 an explosion occurred at a blast-furnace belonging to Messrs. Riley and Son, Mill Fields, near Bilston. One of the twyers was melted off, and the molten metal in the hearth was ejected from the furnace.

At one of the Corbyn's-Hall blast-furnaces, Kingswinford, South Staffordshire, there was an explosion on Sunday morning, which killed two men and seriously injured four others. They were about to proceed with tapping, when a portion of the fore-part of the furnace was blown out with a loud report, and at the same instant a large quantity,—many tons, it is stated,—of molten metal and cinder was forced out with great velocity. The cause of the accident was the leakage of a twyer and the consequent injection of water into the liquid contents of the hearth. (*The Times*, May 11th, 1859.)

At one of the three blast-furnaces of Messrs. Hickman, Bilston, South Staffordshire, an explosion occurred on Sunday, which killed two men, and severely burnt a third about the feet. It is stated that tapping had been delayed and the liquid contents of the hearth had risen up to the water twyers, when leakage took place, followed by the escape of water into the hearth. Nearly the whole of the molten metal in hearth, which amounted to about 5 tons, was driven out at the fore-part, it is said, "out of the tapping place." (*Illustrated London News*, July 14th, 1860.)

On Friday night, about 9 o'clock, an explosion occurred at No. 5 furnace, Dundyvan Iron-works, near Coatbridge, in the neighbourhood of Airdrie, Scotland. Up to that time the furnace, it is stated, was apparently in first-rate working order. It was conjectured that "in some part of the furnace a quantity of the contents had got incrusted to the side,"—or, *i. e.* scaffolding had taken place,—and that the sudden falling of this forced out the molten matter in the hearth. "Three men and a lad, who were working in front of this, were all overwhelmed in an instant by the liquid mass of scoria and ashes. The scene which followed was heartrending in the extreme. Their clothes were consumed, and nearly every part of their bodies fearfully scorched. Their

cross were portable, and the men ran some distance from the place, but the poor boy could not escape. With some difficulty, however, he was extricated and taken home, but died within an hour afterwards. The three men lingered in excruciating pain till Saturday, when they expired." (*Times*, March 14th, 1861.) From private information which I received, the cause of the accident seems to have been leakage of a twyer.

At the Heyford Iron-works, near Weedon, Northamptonshire, an explosion occurred on Wednesday morning, October 10, at one of the blast-furnaces, whereby one man was killed and another seriously injured. A large quantity of molten iron and cinder was blown out at the fore-part; and such was the force of the explosion, that some of the iron, cinder, and coke, fell at a distance of 200 yards. The accident was clearly traced to the escape of water from a twyer; but a witness at the coroner's inquest deposed, that "he could not say whether the twyer was in any way defective, as the end of it had been destroyed by the action of fire since the explosion." It would have been desirable to have asked this witness how he knew that the destruction of the end of the twyer had not preceded the accident? The foreman of the furnace admitted that the twyer was "burnt," and yet declared that the water was running properly through at 20 minutes before the explosion and immediately afterwards. It was conjectured that the supply of water to this twyer might have failed from some accidental circumstance, such as the obstruction by a weed, or other substance, which had been carried down from the cistern, or by the inadvertent shutting of a cock. (*Times*, Oct. 12th and 14th, 1861.) The fertility of invention which witnesses occasionally display in suggesting possibilities, especially before a coroner's jury, is remarkable as well as amusing.

I have made particular enquiries of persons practically acquainted with the working of blast-furnaces, respecting the causes of explosions like those just described; and the answer has generally been "leaky twyer with rising of the hearth." If the "bear," *i.e.* the ferriferous mass which forms in the hearth, is allowed to accumulate to too great an extent, the bottom of the hearth is liable to be raised in such a degree as to bring even the molten metal in contact with the ends of the water twyers, whereby they are speedily burnt away, and water freely escapes into the furnace. The result will inevitably be an explosion from the rapid generation of steam, and here is a *vera causa* which seems adequate to account for the fact. Some effect may be due to the evolution of hydrogen by the action of the molten metal on the water; but that, I apprehend, will be comparatively small. Leaky twyers may arise from other causes than a rising hearth, as, for example, the unwelding of the iron, the gradual destruction of the end by oxidation, in spite of the cooling effect of the water circulating within, etc. Rising of the hearth was the cause assigned on good authority, both at the Corbyn's-Hall and the Bilston furnaces. It implies neglect on the part of the furnace manager, and arises from the desire to defer the blowing out of the furnace in order to remove the bear and effect necessary repairs to the latest possible period, notwithstanding the risk of explosion thereby incurred. In

future inquests connected with blast-furnace explosions, it is to be hoped that the condition of the hearth will be the subject of special investigation.

I submitted the foregoing observations to my friend, Mr. Menelaus, of the Dowlais Iron-works, and received from him the following valuable comments in reply:—

"I have read the proofs with several of our agents and men who understand such matters, and I give you below the substance of their remarks, with which I quite agree. With regard to explosions in blast-furnaces, we agree with you that the direct cause is leaky twyers. We do not think, however, that the state of the furnace has anything to do with it, and your remarks about furnace managers keeping in furnaces too long are beside the question. Leaky twyers are quite common, and the water from the twyers sometimes even runs out under the tymp harmlessly, as far as causing any explosion. We believe that it is only when the nose of the twyer—being wet—drops off and sinks into the molten iron, or when, through the fall of a scaffold, some wet material is carried down under the surface of the iron, that an explosion can possibly take place. As you well know, in many of the operations in iron-making water is thrown upon the surface of molten iron, such as in the puddling furnaces and the refinery mould. If in throwing water on the iron there is a small portion of cinder or iron in the bucket, it is certain to cause an explosion more or less violent, in some cases fatal to life. The piece of wet material, from the force with which the water is thrown, is carried under the surface of the iron and causes the explosion. A wet bar thrust into the iron has the same effect. The men well knowing this are exceedingly careful in swilling out their buckets, and in obtaining clean water before throwing it on molten iron. With all this care, however, explosions — particularly at refineries — are of frequent occurrence. We have had two persons killed in this way within the last few years, and several violent explosions, not attended with fatal consequences, have taken place.

"You will see that our argument is, that if even all the twyers are leaking—which is sometimes the case—through the water being accidentally stopped for a short period, no explosion will take place; and, knowing the effect of even a small piece of damp material getting under the surface of molten iron in the finery mould or puddling furnace, we argue that explosions in the blast-furnace proceed from the same cause.

"With regard to the cause of leaky twyers, they do not arise from *a rising of the hearth*: from practical reasons this can have no possible influence upon the twyer. Your other explanation is correct. Leaks arise entirely from defective welding in the twyer, from oxidation, and sometimes from internal deposit.

"I come now to explosions outside the blast-furnace, say in the blast pipes and blowing engines.

"When the blowing engine is stopped, the men immediately pull down the nozzles from the twyers, so as to cut off with *certainty* all

[illegible]

[illegible] which open immediately on the stoppage of the engine, and prevent, to a great extent, the accumulation of gas inside the pipes. Still, with all these precautions, [illegible] explosions sometimes occur."

I again addressed Mr. [illegible] on this important subject, and subjoin [illegible] letter in answer:—

"I have had another talk with our people over the matter relating to explosions in blast-furnaces.

"If your theory as I understand it is correct, explosions in blast-furnaces would be of frequent occurrence. Bad hearths are but too common, not because there is a large 'horse' (i.e. bear) in the hearth, but on account of irregular working and scaffolding of the furnace, occasioned mainly through bad filling; the bottom of the hearth rises temporarily, sometimes even above the line of twyers. When this happens, that is, when it becomes impossible to blow with the twyers in the ordinary position, new twyers are put in at a higher level, and they are lowered as the bottom falls so as to keep them within from 6 in. to a foot above the surface of the accumulation in the hearth, until the hearth comes to its original level. The old twyers are then opened, and they are found generally uninjured.

"First, you will observe that owing to ordinary and temporary derangement of the working of the furnace the iron sometimes rises above the twyers and shuts them, often leaving the twyers uninjured; and as a fact, a twyer leaking when the furnace is in this condition does not necessarily cause an explosion.

"Now, in working a number of furnaces, we frequently have the iron rising over the twyers, as explained above, and we frequently also have a twyer leaking when the furnace is in this condition; but there has been no instance of an explosion in a furnace at Dowlais from this cause; and owing to scarcity of water in the summer, and to its dirty condition, we have, unfortunately, often leaky twyers.

"I am quite satisfied that water is the cause of explosions in blast-furnaces when they occur. I believe there is no instance of an explosion occurring in a cold-blast-furnace where water twyers are not used. If you suppose the end of a twyer suddenly burnt off, that is, a simple opening from the twyer into the furnace, no explosion will take place,

unless, as I believe, a portion of wet or damp material gets under the surface of the iron. If an explosion could be possibly caused by even a large volume of water being projected under pressure into the furnace, we should have them certainly every month. Of course it is difficult to understand how a small bit of wet cinder or iron, getting under the surface of molten metal, can be the cause of such violent explosions as sometimes occur, but there can be little doubt, from our experience in refinery accidents, that they are occasioned in this way."

The following singular instance of an explosion in France has been recorded by M. Sauvage.[7] Torrefied wood was the fuel used, and the waste gas was taken off at the top. The furnace worked irregularly. A minute before the explosion a projection took place at the twyer, the twyer-hole having always remained open. The gases which surrounded the hot-blast apparatus exploded, and a current of gas escaped from the tymp. Then began projections from the mouth which lasted about two minutes. The furnace was almost entirely emptied. At the same moment also blue flames proceeded from the passages and cracks in the brickwork. It was supposed that, scaffolding having occurred, a quantity of wood suddenly dropped down into a much hotter part of the furnace, when the result would be the generation of a large amount of gaseous matter, which, being imprisoned, as it were, in the pasty materials of the furnace, might cause a series of explosions.

An explosion occurred at a blast-furnace at Vanvey, Côte-d'Or, France.[8] Charcoal was the fuel employed, and the waste gas was taken off by an arrangement which is stated to have caused an irregular distribution of ore and fuel, and consequent tendency to scaffolding. After a long continuance of irregularity in the working of this furnace, as manifested by frequent intermittence in the descent of the charges, and by corresponding irregularity in the daily make, the molten pig-iron and slag, which filled the hearth, were suddenly expelled with great force from the tymp. Three men, who were preparing for the cast, were seriously injured, and one died. The accident was attributed to a sudden fall of a mass of materials, which had scaffolded.

The subjoined account appeared in the *Times* of May 25th, 1859, quoted from the *Birmingham Post*:—

On Sunday afternoon, about 5, an explosion took place at Earl Granville's Old Blast-Furnaces, Etruria-road, Hanley, which, though happily involving no loss of life, has occasioned the sacrifice of a large amount of money and property, and the labour of a number of men for some time to come. It appeared that while the men were casting from one of the furnaces, the engine which supplied the hot air for blasting stopped, and either the valve was neglected to be turned to shut off the hot air into the receiver, or the valve was out of order and would not act, or from some other cause, which has not been yet ascertained, the foul gas and sulphur[9] which had accumulated in the furnaces

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[7] Ann. des Mines, 3. s. 19. p. 167. 1841.

[8] Ibid., p. 179.

[9] The word sulphur is commonly applied in Staffordshire to various agents of mischief which may not contain a particle of that element. Thus fire-damp is always designated sulphur by the Staffordshire colliers. This use of the word is, probably,

passed through the pipes, the valve, and into the receiver, and being heated by the pipes, it caused the receiver to explode with terrific effect. The receiver and part of the engine were shattered to atoms, and fragments were strewn in all directions, some to the middle of the old race-course, several hundred yards off. The building in which the engine and receiver stood, which was a three-storied one and strongly built, was shaken to its foundations; the roof raised two feet, but directly dropped to its former position, except in the centre, just over the engine, where a large portion was blown clean away; the floors and ceilings were broken into shreds, the walls were shaken and split on each side, and a good portion of that side nearest the engine tumbled to pieces; the windows were shattered to bits, and the whole building and extensive machinery for a time rendered useless. The explosion was heard at a distance of between two and three miles, and it shook the earth for several hundred yards around. Fortunately no one was injured, though some sixty men were at work in the casting-house, fifty yards from the scene of the disaster, and the engineer was at the moment engaged in oiling some portion of the machinery at the top of the building. The noise attracted to the spot some hundreds of people, who appeared to look with great interest on the ruins which the explosion had caused. The men were set to work yesterday morning to clear away the debris, and as soon as possible, we believe, a new house and new machinery will be constructed; but it will be a long time before the damage can be fully repaired, or the men who have been by this accident thrown out of employ be again at work. We have heard that the loss which will be sustained by this explosion will be nearly 10,000*l*., but it is impossible in the present state of affairs to make a correct calculation: probably that sum is an over estimate.

Poisoning by the Gas accidentally escaping from the Blast-furnace.

This is a subject on which it is important that persons having the direction of blast-furnaces should be correctly informed; and I, therefore, present *in extenso* the following account of a remarkable case of fatal poisoning by the gas evolved from these furnaces, which appeared in the *Times* of December 6th, 1853.

"On Saturday last Mr. T. Badger, coroner of the Sheffield district, held a judicial inquiry at Elsecar into the circumstances attending the deaths of Phœbe Sadler, aged 53; her daughter and son, Ann Sadler, aged 19, and John Sadler, 15; and a lodger named Warrick, aged 48; all of whom were suffocated in their bedrooms during the night of

derived from the superstitious belief of former times, that the devil was the prime cause of the disasters connected with the operations of fire in metallurgical works and collieries. The devil and brimstone are still invariably associated in the popular mind; and nursemaids even now-a-days inspire children with terror by declaring that the "Devil is at their elbow," and they "smell the brimstone."

The foregoing description of the explosion is not so intelligible as it might be; yet enough is stated to render it probable that the accident was caused by the efflux of the gas of the furnace and its accumulation in the blast-pipes and regulator to a sufficient extent to produce an explosive mixture therein with atmospheric air.

Thursday last. Elsecar is a populous village situate between Rotherham and Barnsley. The Elsecar Iron-works are close to the village, and about a mile distant are the Milton Iron-works. Both properties belong to Earl Fitzwilliam, and are occupied and worked by Messrs. W. H. and G. Dawes. The most northern of a short row of houses abuts upon one of the blast-furnaces at the Elsecar Iron-works. This house was occupied by the four deceased persons and Benjamin Sadler, aged 12, son of Phœbe Sadler. Benjamin Sadler is employed at the Milton Iron-works, and, being on the 'night shift,' left home to go to his work a little after six o'clock on Thursday evening. The rest of the family retired to rest about ten o'clock, being then in their usual health. Mrs. Sadler and her daughter and son, the latter of whom was lame, occupied a bed in the front bedroom, and Warrick, the lodger, slept alone in the back bedroom. Benjamin Sadler returned from his work at half-past seven o'clock on Friday morning. His knocks for admittance received no answer, and after alarming some of the neighbours he entered the house through the kitchen window, and went up stairs. The spectacle which there met his sight smote his young heart with dismay. Mother, sister, brother, and lodger,—all were corpses. The lodger was lying upon his back on the floor at the foot of his bed; Mrs. Sadler and her son John were lying at the foot of their bed, clasped in each other's arms; the sister lay on the bed, having, to all appearance, passed undisturbedly from the slumber of repose to that of death. All the rooms were filled with white vapour, and the air was strongly impregnated with sulphur. Several persons who entered the house shortly after the boy observed white vapour issuing from crevices in the wall just above the floor both of the house and kitchen. The bodies appeared to have been dead five or six hours. The following is the evidence of Mr. James Haywood, professional chemist, Sheffield:—

"'I have this (Saturday) afternoon examined the premises where the dead bodies are lying. The house consists of two lower rooms and two bedrooms, the north wall of the lower rooms being built against the side of the stack of the blast-furnace, and the same wall of the upper rooms being connected with the furnace by an arch and a quantity of brickwork three feet thick. The level of the ground is about twenty feet from the bottom of the furnace. At this point, immediately connected with the house-wall, there is a large crack, discharging vapour, in which I could recognize the odour of cyanide of potassium. There is another crack in the brickwork of the house-wall, through which also this vapour is passing. The brickwork of the wall is so loose that any discharge of vapour or gas from the furnace might find its way not only through this crack, but through many others. I have no doubt, from the evidence I have heard, as well as from having detected cyanide of potassium, that the deaths of these persons have resulted from inhaling the vapour of cyanide of potassium. My opinion is confirmed by the following facts:—There being a fire burning in the house all night would show that they have not died from inhaling combustible gases, as the fire would have inflamed any such gases

issuing from the furnace in a sufficient quantity to cause death: and to my knowledge there is always a large quantity of vapour of cyanide of potassium in the lower part of a smelting furnace, which vapour is highly poisonous. A very small quantity—I should say one ounce—of cyanide of potassium converted into vapour, would kill the deceased.'

"The furnace-stack is old and dilapidated, being screwed together with girder rods to prevent its opening from being expanded with heat, but it does not appear that any annoyance had been previously suffered by the inmates of the house from sulphur. The Jury returned a verdict—'That death had been caused by inhaling the vapour of cyanide of potassium.'"

Dr. Taylor is of opinion that death in this case was due to the action of carbonic oxide, and not of cyanide of potassium: for, he observes that as this salt, which is only evolved from the lower part of iron-furnaces, is not volatile below a white-heat, it cannot be carried far without condensation: and it is, therefore, difficult to conceive how it could exist and spread itself in the form of a respirable vapour through the air of the apartments in which the deceased were sleeping.[1] Now, admitting that the salt would be speedily condensed after escaping from the furnace, yet it might remain diffused through the air in a state of extremely fine division, and be conveyed, I apprehend, even to a considerable distance. Thus, chloride of sodium, it is well known, has been transported from the sea in suspension in the atmosphere far inland. Moreover, in the laboratory, solid matter, which is perfectly fixed at ordinary temperatures, is often finely diffused through the air, so as to be everywhere sensible by its action upon the organs of respiration. When, for example, only a minute fragment of sodium is burned even in a large apartment, an irritating effect is almost immediately produced upon those organs, due to minute particles of soda floating in the air. Hence, the argument of Dr. Taylor against the supposition of poisoning by cyanide of potassium, in the case in question, on the ground of its non-volatility, except at a very high temperature, is not so conclusive as it might at first appear. Besides, that argument is further opposed to the positive statement of the chemical witness that he recognised the odour of cyanide of potassium in the vapour discharged from a large crack in the furnace, and that this vapour was seen to pass through another crack in the brickwork of the house-wall adjoining. There was nothing, so far as I can judge, in the appearance of the corpses incompatible with poisoning by cyanide of potassium. In one case, of a woman killed by this poison, recorded by Dr. Taylor, "the appearance of the body was so natural even on the day following death, that some of her friends supposed there might still be life."[2]

But, whatever opinion may be entertained concerning the verdict of

[1] Medical Jurisprudence, by Alfred S. Taylor, M.D., F.R.S. 2nd ed. p. 715. I have pleasure in acknowledging the kind and prompt assistance of Dr. Taylor in furnishing me with various references to published papers on the poisonous action of carbonic oxide.

[2] Op. cit. p. 713.

the coroner's jury in the Elsecar case, that death was occasioned by the inhalation of cyanide of potassium, it is certain that any of this salt which might have found its way from the furnace into the adjoining dwelling-house must have been accompanied with another poisonous agent in an amply sufficient degree rapidly to destroy life, and that is carbonic oxide. It is this gas, or the nitrogen from deoxidized air, that Dr. Taylor considers the more probable agent of destruction in the case in question. Nitrogen kills simply by the negation of oxygen, whereas carbonic oxide is stated to be a formidable positive poison. As this gas now plays so important a part in many metallurgical operations, it is desirable that correct information should prevail upon the subject.

Dr. Christison states that "this gas certainly appears to be very deleterious when breathed by man," and, in proof, he cites the following experiments upon it, which were made in Dublin.[3] One gentleman, after inhaling it two or three times, was seized with giddiness, tremors, and an approach to insensibility, succeeded by languor, weakness, and headache of some hours' duration. Another gentleman, having previously exhausted his lungs, inhaled the pure gas three or four times, when he was suddenly deprived of sense and motion, fell down supine, and continued for half an hour insensible, apparently lifeless, and with the pulse nearly extinct. Various means were tried for rousing him, without success; till at last oxygen gas was blown into his lungs. Animation then quickly returned; but he was affected for the rest of the day with convulsive agitation of the body, stupor, violent headache, and quick irregular pulse; and after his senses were quite restored, he suffered from giddiness, blindness, nausea, alternate heats and chills, succeeded by feverish, broken, but irresistible sleep.

In 1841, M. Dupuis Delcourt, a French aerostat, ascended in a balloon inflated with gas produced by the action of water on incandescent charcoal, and which consists chiefly of carbonic oxide and hydrogen. The ascent was rapid, and gas escaped from the orifice immediately above the car. Scarcely had he commenced his fourth barometrical observation than he became senseless, and had not completely recovered when the balloon reached the earth. But he again lost consciousness in consequence of the imprudence of rustics, who, having run to his assistance, tore off the lower and narrow extremity. These persons were themselves victims, and suffered from incipient asphyxia. Delcourt was not restored to his senses until withdrawn from under the balloon, and he continued seriously indisposed for twenty-four hours afterwards.[4] Hydrogen is comparatively innocuous, and may be respired for a short time with impunity; and the poisonous effect in this instance was attributed solely to carbonic oxide. Some carbonic acid must have existed in the gas, but experiments are cited to show that it was not in sufficient proportion to have produced any decided poisonous effect.

[3] A Treatise on Poisons. By Robert Christison, M.D. 3rd ed. p. 754. 1836.

[4] De l'Emploi Industriel de l'Oxyde de Carbone et de l'Action de ce Gaz sur l'Economie Animale. Par M. Alph. Guérard. Annales d'Hygiène Publique et de Médecine Légale. 30. p. 52. 1843.

According to Leblanc, atmospheric air containing only 4 % or 5 % of its volume of carbonic oxide destroys a sparrow instantly; and when it only contains 1 % it kills a bird in about two minutes. If, at the moment of apparent death, the animal is withdrawn from this deleterious influence, it may recover; but frequently, the "phenomena of paralysation" do not disappear until after the lapse of several hours. On the contrary, atmospheric air mixed with 1 % or 2 % of marsh-gas may be respired with apparent impunity during a considerable time.[3] Leblanc found that air, rendered fatal to life by the combustion of charcoal, had the following composition by weight:—

Carbonic oxide	0·54
Marsh-gas	0·04
Carbonic acid	4·61
Oxygen	19·19
Nitrogen	75·62
	100·00

In such an atmosphere a dog fell exhausted in 10 minutes, and in 20 minutes died, although a candle still burned with undiminished brightness, and was not extinguished until 10 minutes after the death of the animal. The poisoning in this case was attributed to this small proportion of carbonic oxide, as the amount of carbonic acid was insufficient to destroy life so rapidly.

Bernard, a well-known experimental physiologist, has investigated the action of carbonic oxide on the animal system. He pronounces it to be "one of the most poisonous gases known," and that its effect is immediate, yet only transitory; and he considers that in cases of death from exposure to the fumes of charcoal it has been the chief agent of destruction, and not carbonic acid, as has commonly been supposed.[4] In support of this conclusion he adduces Leblanc's experiment just described, and others by himself. A bird put into atmospheric air containing 6 % of its volume of carbonic oxide was immediately convulsed and died in about three minutes, the convulsions lasting all the while. In poisoning by carbonic acid, on the other hand, convulsions are an abnormal symptom. Bernard showed that blood reddens in contact with carbonic oxide as it does with oxygen, but blackens in the presence of carbonic acid; and that the blood of animals poisoned by the inhalation of carbonic oxide is red. This reddening of the blood is persistent, and Bernard has occasionally observed it to continue longer than three weeks. Whereas, blood reddened by oxygen acquires, when left to itself, the dark colour of venous blood, except at the surface where it is in direct contact with atmospheric air. According to the experience of Bernard, red blood only escapes from the vein in poisoning either by carbonic oxide or prussic acid.

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[3] Recherches sur la composition de l'air confiné. Par M. Félix Leblanc. Ann. de Chim. et de Phys. 3. s. p. 239. 1842.

[4] Leçons sur les Effets des Substances Toxiques et Médicamenteuses. Par M. Claude Bernard, Membre de l'Institut de France. 1857, p. 157.

The late Mr. Truran, engineer of the Dowlais Iron-works, lost his life through the escape of the waste gas of the blast-furnace. I am indebted for the following account of the accident to Mr. William Menelaus, manager of the works:—

"Mr. Truran's death happened in the following way. A portion of the ground in front of our old works furnaces is an old cinder-tip, where the cinders from the furnaces had been thrown when they were originally blown in. Through this cinder-tip we made a large brick culvert for conveying the waste gases to the forge-boilers. We find these culverts cheaper than pipes, and, on the whole, they answer well. Mr. Truran's office was built upon the old cinder-tip, about from ten to fifteen yards from the side of the culvert. A few days after the gas had been turned through the culvert Mr. Truran went to his office about mid-day. In the evening, when he did not return home as usual, his family made search for him, and he was found lying dead on the floor of the office. He had been sitting at his desk with some drawings before him, and he had evidently, from having been overcome by the gas, fallen from his seat. There could be no doubt that he was poisoned by the gas. I went with the jury to the office, which had been locked up from the time of his death, and the smell of the gas was quite perceptible, and the atmosphere of the office so disagreeable that we were obliged at once to get into the open air. As our forges are below the level of the bottom of the furnaces, the gas in the culverts is under considerable pressure, and no doubt had escaped through the new brickwork and the loose cinder-tip into the office. Now there is little or no leakage."

Mr. Sandberg informs me that several fatal cases of poisoning by the gas of the blast-furnace have occurred in Sweden. There was a sad instance of the kind in 1856, at the iron-works at Ed in Småland. Owing to a defective damper some of the gas accidentally escaped from the top of a gas mine-kiln unignited, when one of the fillers was overcome by it and fell in with his barrow; and another filler, not perceiving the accident, discharged a barrow upon him. This man also inhaled the gas, and was found dead at the top of the kiln. A third man was affected, but recovered through speedy medical assistance. At this period the extremely poisonous nature of the gas was not known; but of late, great precautions having been exercised, no similar accidents have taken place.

What has now been advanced clearly establishes the fact, that carbonic oxide is a formidable poison, and that atmospheric air containing only a very small proportion of it, even far less than would suffice to produce an explosive mixture, cannot long be inhaled without danger to life. The opinion of the chemical witness, therefore, at the Elsecar inquest, that carbonic oxide could not have been the cause of death, because there had been a fire in the house which would have ignited it, necessarily falls to the ground. The probability, it seems to me, is in favour of the conclusion that carbonic oxide, rather than cyanide of potassium, destroyed the lives of the unfortunate victims. With regard to the suggestion of Dr. Taylor that nitrogen may have been

the agent of destruction. I have only to remark that carbonic oxide must have been present in considerable quantity, and with such a potent *vera causa* at hand, there appears to be no necessity for the nitrogen hypothesis.

Blast-furnace managers, especially where the waste gas is taken off and economized, should bear in mind the poisonous effect of this gas even in small quantity. Should any accident arise from its inhalation, the patient should be instantly removed from its influence, and conveyed where he may breathe as pure air as possible. Everything about the neck should be either removed or loosened, and the body should be kept warm by friction or otherwise. We have seen that inflation of the lungs with oxygen appeared to save life in one case; but in iron-works, even when provided with chemical laboratories, this remedy could hardly be prepared in time, and it might, therefore, be desirable to keep a caoutchouc bag filled with oxygen always at hand.

ANALYSES OF VARIOUS KINDS OF PIG-IRON.

SPIEGELEISEN.

This variety of pig-iron is so distinct that it will be considered apart. It is obtained by smelting spathic or other ores rich in manganese, with charcoal as the fuel for what are considered the best qualities. Many details on this subject will be found in the description of the Prussian iron-works by Dr. Wedding in the sequel. The following selection of analyses of spiegeleisen from different localities will suffice for illustration:—

From Müsen.—It is largely produced from the famous spathic ore of Stahlberg, near Müsen, worked by the Müsen and Cologne Mining Company. The following elaborate analysis of this spiegeleisen is by Fresenius[7]:—

Iron	82·860
Manganese	10·707
Nickel	0·016
Cobalt	trace
Copper	0·066
Aluminium	0·077
Titanium	0 006
Magnesium	0·045
Calcium	0·091
Potassium	0·063
Sodium	trace
Lithium	trace
Arsenic	0·007
Antimony	0·004
Phosphorus	0·059
Sulphur	0·014
Nitrogen	0·014
Silicon	0·997
Carbon	4·323
Silica, existing in the intermingled slag	0·475
Oxygen combined in the bases of the slag, viz., alumina, protoxide of iron, protoxide of manganese, lime, magnesia, and alkalies	0 190
	99·954

[7] From a printed circular of the Müsen Company. Date of the analysis Aug. 6, 1862.

I am somewhat puzzled to interpret the meaning of the statement under the last item. The oxygen required for the oxidation of the aluminium, magnesium, calcium, and potassium amounts to 0·149; and if Fresenius considered these metals to exist as oxides in intermingled slag, I do not understand why they should have been tabulated as if in the metallic state. Nor is it clear to me how the proportion of intermingled slag should have been quantitatively determined with so much precision. But Fresenius has had great experience in analysis, and would assuredly not publish results except on good evidence. There may possibly be errors due to the scribe or the printer employed by the Müsen Company.

Peters has given the following average composition of the spathic ores smelted by the Müsen Company:—[8]

Silica	1·62
Alumina	1·63
Sesquioxide of iron	2·75
Protoxide of iron	52·12
Protoxide of manganese	0·83
Lime	1·75
Magnesia	2·29
Oxide of zinc	0·04
Carbonic acid	35·92
Phosphoric acid	0·54
Bisulphide of iron	0·22
Water	0·45
Organic matter	0·39
	100·55
Iron % in the raw ore	42·59
do. roasted ore	61·80

From Theresienthal, in Bohemia.—By Professor R. Richter, Leoben, Styria.[9]

Carbon	2·311
Silicon	2·732
Manganese	22·183

No other details are given. This is the only analysis of spiegeleisen which I have found containing anything approaching so large an amount of manganese. The proportion of carbon is as unusually small as that of silicon is large; and, probably, the latter should be regarded as replacing the former. When Professor Tunner was in London, in 1862, I informed him that I had a specimen of spiegeleisen from the United States containing more than 11% of manganese; but he appeared somewhat sceptical as to the fact. However, while he was yet here the preceding analysis made in the laboratory of the Mining School, over which he himself presides, was published.

From Jauerburg, in Krain.—By Professor R. Richter, Leoben.[1] This is interesting as having been produced in the smelting of slags (Frischschlacke) formed during the conversion of pig into malleable iron in the charcoal hearth or finery.

Silicon	1·902
Manganese	7·578
Sulphur	0·073

[8] Jahres-Bericht. Wagner, 1857, p. 5.
[9] Berg-u.-Hüttenmännisches Jahrbuch. Wien, 1862. 9. p. 294.
[1] Op. cit. p. 295.

From New Jersey, U. S.—By the late Mr. T. H. Henry, and communicated by Mr. E. F. Sanderson, of Sheffield. It is a highly characteristic specimen, and was obtained in smelting Franklinite.

Carbon	6·[illegible]
Silicon	[illegible]
Manganese	[illegible]
Sulphur	[illegible]
Iron by difference	[illegible]·383
	100·000

Mr. Henry remarked that the amount of carbon and manganese was much larger than he had previously met with, and that the number assigned for the former might be a little too high, although he had adopted the lowest quantity found.

The following analysis of what was designated "spathose pig" has been made and communicated by Mr. E. Riley. The locality was not stated:—

Silicon	0·[illegible]
Manganese	11·[illegible]
Sulphur	traces
Phosphorus	0·1[illegible]
Iron	84·540
	96·374

The carbon was not determined, but if it be deduced from the deficiency it will be 3·626.

From Germany, the precise locality not stated.—By Mr. Tookey, in my laboratory. The specimen was highly characteristic.

Carbon	4·770
Silicon	0·820
Manganese	11·120
Sulphur	traces
Phosphorus	0·134
Copper	0·310

Nickel and cobalt were sought for, but not detected.

From Tow Law, Durham.—It was produced in Messrs. Attwood and Company's furnaces from ores Nos. 3 and 4 in Table V. of spathic carbonates. It is bright white, and largely lamellar on fracture, but has not the characters of typical specimens of spiegeleisen, like that from Müsen. The cleavage planes, especially when examined under a lens and under varying directions of incident light, appeared very minutely granular, suggesting somewhat the appearance of the cleavage planes of the fracture of zinc containing iron. The analysis was made by Mr. Tookey in my laboratory.

Carbon	4·100
Silicon	0·230
Manganese	2·370
Sulphur	0·030
Phosphorus	0·073
Copper	0·014

Two determinations of the silicon were made: in the first 101·2 grains of the iron gave 0·54% of silica, and in the second 105 grains of the iron gave 0·56% of silica. Three determinations of the man-

ganese were made, and the results were 2·264%, 2·48%, and 2·36% respectively.

	I.	II.	III.
Carbon	2·795	2·390	3·040
Silicium	4·414	5·730	3·800
Sulphur	0·039	0·119	0·058
Phosphorus	0·099	0·131	0·102
Titanium	traces	0·020	
Nickel with traces of cobalt		0·040	
Traces of copper and lead			
Manganese	1·837	1·330	3·300
Iron	90·584	90·210	89·380
	99·768	99·970	99·680

Analyses by Mr. Riley.—Tow Law grey pig No. I. found specially adapted for the Bessemer process, and made from decomposed spathic ore. No. II., glazed pig, found better for the Bessemer process than No. III. This pig-iron was smelted with coke.

In the Zollverein department of the International Exhibition of 1862 were specimens of spiegeleisen smelted with a mixture of charcoal and coke, and with coke alone. Dresler, of Siegen, exhibited specimens of coke spiegeleisen made from a mixture of $\frac{8}{10}$ brown iron ore, and $\frac{8}{10}$ spathic ore. For 100 parts by weight of spiegeleisen were consumed on the average 120 of coke; but it was reported that with certain qualities of ore, from 80 to 100 parts of coke sufficed to make 100 parts of spiegeleisen. There are two small furnaces which only continue in blast for a year at a time, or as it is termed a campagne. During the first 3 months charcoal alone is used as fuel, and coke during the remaining 9 months. The average daily make of both furnaces was about 10 tons or so. The cleavage planes of spiegeleisen, made entirely with coke as fuel, appeared somewhat rough on the surface as compared with those of characteristic charcoal spiegeleisen. It has been erroneously stated that the intersecting thin plates of the latter description never occur in coke spiegeleisen. The slag or cinder accompanying the formation of spiegeleisen, however made, is always green from the presence of protoxide of manganese in large quantity. Some of the specimens of spiegeleisen in the Zollverein department of the Exhibition were really magnificent. The thickest slab was $7\frac{3}{8}$ in. in thickness.

From Eisenerz, Styria.—The following are analyses, by Widtermann, of pig-iron from a blast-furnace at Eisenerz, such as was employed at the Krumbach Iron-works, near Reichenau, for conversion into malleable iron in a charcoal finery, with slag bottom (Schwallboden).[3] It is the variety designated by the Germans "grossluckige Floss." It is cast into rectangular plates 2 in. or 3 in. thick; it is bright white, but not specular on fracture, and often contains numerous cavities (löcherig or luckig). With the exception of being richer in manganese, it is very similar in composition to the last-described specimen from Tow Law.

[3] Jahresb., L. u. K., 1853, p. 722.

It was made, I presume, from spathic carbonate, but the details of its production are not stated.

	I. a.	I. b.
Carbon	3·79	3·83
Silicon	0·34	0·41
Sulphur	0·02	0·02
Phosphorus	0·07	0·04
Manganese	1·05	0·98
Calcium	0·05	0·07
Magnesium	0·02	0·01
Iron	94·57	94·68
	99·92	100·04

Analyses of Pig-iron made from Magnetic Iron Ore.

	I.	II.
Carbon	4·809	4·20
Silicon	0·176	0·08
Sulphur	trace	trace
Phosphorus	0·122	0·05
Manganese	1·987	0·10
Iron	92·906	95 57
	100·000	100·00

I. Smelted with charcoal in Sweden, from Dannemora ores of magnetic oxide of iron. It is from this pig-iron that the renowned Swedish "Hoop-L" bar-iron is produced. The analysis was made by the late Mr. T. H. Henry for Mr. S. H. Blackwell, by whom it has been communicated. II. This was sent to me as spiegeleisen: it was white and lamellar on fracture, somewhat like antimony, except near the upper surface, where it was grey and finely granular; there were no bright cleavage planes as in good characteristic spiegeleisen. Only the white portion was analysed. The analysis was made by Mr. Tookey in my laboratory. I presume that this specimen had been derived from magnetic iron ore, although it was not so specified.

Analyses of Pig-Iron made from Red Hæmatite.

Per cent.

		I.	II.	III.	IV.	V.
Carbon	combined	none	small, but not determined	small, but not determined	0·35	3·419
	graphitic	3·22	2·24	2·30	1·86	
Silicon		3·02	2·77	2·72	2·63	1·634
Sulphur		none	0·01	0·05	0·10	0·148
Phosphorus		0·06	0·05	0·05	0·03	trace
Manganese		0·11	0·07	trace	0·07	trace
Arsenic		traces	minute traces	minute traces	minute traces	
Copper		traces				

I., II., III., IV. were foundry-pig, described as Nos. 1, 2, 3, 4, respectively, made by the Hæmatite Iron Company, Whitehaven, Cumberland. The smelting, I believe, was with hot-blast, although it is not so stated. The distinction in external characters between II.

and III. was not well marked, and analysis shows that they were nearly identical. All these analyses were made at the Arsenal, under the direction of my friend Mr. Abel. They were published in the Blue-book entitled 'Cast-Iron Experiments.'[3]

The ore stated to have been used in producing these samples of pig-iron was analysed, and the results are as follow:—

Sesquioxide of iron	98·71
Oxide of manganese, Lime, Phosphoric acid	traces
Silica, as quartz	1·00
	99·71
Metallic iron %	69·10

The fuel consisted of equal parts of coke from Newcastle and of coke manufactured at the Works. The Newcastle coke was hard and lustrous, and contained 0·80% of sulphur, and yielded 4·45% of light red ash, consisting of silicate of alumina, with lime, sesquioxide of iron, and traces of magnesia and phosphoric acid. The Whitehaven coke was more friable than the Newcastle coke; it contained 1·38% of sulphur, and yielded 12·16% of ash, similar in composition to that stated above, but without any appreciable amount of phosphoric acid.

The flux employed consisted of a mixture of Whitehaven limestone and black shale of the coal-measures, consisting of clay and carbonaceous matter without an appreciable amount of sulphur. The limestone was fine-grained, crystalline, and light brownish-grey; it contained shells of *terebratula*. Its composition, after drying at 100° C., was as under:—

Carbonate of lime	97·63
Carbonate of magnesia	1·03
Carbonate of protoxide of iron	0·24
Carbonate of protoxide of manganese	0·11
Sulphate of lime	0·07
Phosphate of lime	trace
Alumina	0·10
Silica, chiefly as sand	0·76
Carbonaceous matter	0·06
	100·00

The chief peculiarity of the preceding samples of pig-iron is the large proportion of silicon which they contained. I have previously discussed the condition under which silicon passes into the pig-iron; and that condition, it will be remembered, is the presence of much free silica in the ore unaccompanied with sufficient basic matters for its neutralization. The hard red hæmatites often contain free silica in comparatively large proportion, but in the specimen analysed the

[3] July 30th, 1858. As I shall have frequent occasion to refer to this valuable series of analyses, I shall in future, for the sake of abridgment, indicate the references by the initials A. W. (Arsenal, Woolwich).

amount of silica is very small. Yet the pig-iron was highly siliceous. Now the silicon could, obviously, have only been derived from the ore; and the conclusion to be drawn is, that the ore analysed was a *picked specimen*, and not a true sample.

V. The analysis was made by the late Mr. T. H. Henry for Mr. [illegible] H. Blackwell, by whom it has been communicated. It was considered as a typical description of "very good and strong, but red-short, iron." It was produced from Cleator Moor hæmatite, Cumberland, but no details were given.

	Per cent.
	I.
Carbon, graphitic	[illegible]
Silicon	[illegible]
Sulphur	[illegible]
Phosphorus	[illegible]

(A. W.) specified as "British charcoal iron," made by Messrs. Harrison, Ainslie, and Co., at the Newland Furnaces, near Ulverstone.

The ore was red hæmatite, and the fuel charcoal. This variety of pig is in demand for the manufacture of "malleable cast-iron."

ANALYSES OF PIG-IRON MADE FROM BROWN HÆMATITE.

	Per cent.		
	I.	II.	III.
Carbon, graphitic	3·24	[illegible]	2·15
Silicon	[illegible]	4·25	1·18
Sulphur	0·04	[illegible]	0·12
Phosphorus	0·19	[illegible]	0·19
Manganese	1·45	1·04	trace

I., II., III. (A. W.), were Nos. 1, 3, and 4 pig, respectively, made by the Weardale Iron Company, Durham, from ores of which an analysis has been given in Table V. It is not stated whether hot or cold blast was employed. No. I. was tested for lead, and found to contain a very minute trace.

The fuel was hard and lustrous coke, which contained 0·60 % of sulphur, and yielded 5·16 % of red ash, consisting of silicate of alumina, with sesquioxide of iron and a little lime.

The flux was slaty-grey crystalline limestone, presenting impressions of fossil shells. Its composition after drying at 100° C. was as under:—

Carbonate of lime	95·55
Carbonate of magnesia	3·20
Carbonate of protoxide of iron	trace
Phosphate of lime	0·12
Sand and clay	0·90
Carbonaceous matter	0·23
	100·00

Mr. Abel directs attention to the "somewhat anomalous" amount of silicon in No. II., but without suggesting any explanation of the fact.

	Per cent.		
	I.	II.	III.
Carbon, graphitic	3·26	3·08	3·354
Silicon	2·34	2·18	1·802
Sulphur	0·04	0·06	0·230
Phosphorus	0·14	0·14	0·126
Manganese	0·23	0·14	..

I., II. (A. W.), described as No. 1, and grey-forge pig, respectively, made at the Forest of Dean Company's Park End Iron-works, near Lydney, Gloucestershire, but whether with hot or cold blast is not stated.

It is reported that the ores smelted were "all hæmatite;" so that, I presume, brown ores of the Forest of Dean were alone used in producing these samples of pig-iron. Analyses of these ores will be found in Table III.

The fuel was coke, made from Forest of Dean coal; it contained 0·90 % of sulphur, and yielded 8·2 % of ash, consisting of silica, alumina, sesquioxide of iron, lime, and magnesia.

The flux was burnt shale, of a reddish colour, and presenting impressions of fossil ferns; it consisted of silicate of alumina, with sesquioxide of iron and a little lime and magnesia.

III. The analysis was made by the late Mr. T. H. Henry for Mr. S. H. Blackwell. The pig-iron was produced at Cinderford, Forest of Dean, but no other details were given. This pig produces a good, strong, but red-short, iron.

	I.	II.
Carbon	2·891	4·406
Silicon	0·830	1·035
Sulphur	0·005	1·060
Phosphorus	..	0·002
Copper	trace	0·015
Aluminium	..	0·041
Calcium	..	0·016
Iron	96·274	93·425
	100·000	100·000

I. The analysis was made by Svanberg.[4] The pig-iron was smelted in the Juniata Furnace, Williamsburg, U.S., with anthracite. The ore was a cellular variety of brown iron-ore, resulting from the decomposition of carbonate of protoxide of iron.[5] The width of the furnace was 8 ft. across the boshes, and the make 60 tons per week.[6]

II. This analysis is also by Svanberg. The pig-iron is simply specified as from the Lehigh Company's blast-furnace. Lesley mentions the Lehigh Valley Iron Company's steam-furnace (*sic*), and states fine brown hæmatite ore was therein smelted. I presume that this pig-iron was produced at the furnace above-named.

Analysis of Pig-Iron made chiefly from a Mixture of Red and Brown Hæmatite.

	Per cent.
Carbon, graphitic	3·15
Silicon	1·05
Sulphur	0·05
Phosphorus	0·29
Manganese	1·14

[4] Berzelius, Jahres-Bericht, 1846, p. 198.

[5] Geology of Pennsylvania. State Survey. Rogers, 1. p. 358.

[6] The Iron Manufacturer's Guide to the Furnaces, Forges, and Rolling Mills of the United States. By J. P. Lesley. New York, 1859, p. 60.

(A. W.) Specified simply as "pig-iron, first melting," made by Messrs. Firmstone and Co. at the Lays Iron-works, near Dudley, but whether with hot or cold blast is not stated.

The charge of ore consisted of Ulverstone hæmatite (anhydrous sesquioxide of iron) 25 cwts., Forest of Dean hæmatite (hydrated sesquioxide of iron) 5 cwts., "hydrate of iron" (? brown iron ore from Frogball) 25 cwts., roasted Gubbin ironstone 10 cwts., and roasted Bottom whitestone 5 cwts.

The fuel consisted of equal parts of Thick-coal (Staffordshire), Derbyshire, and Durham coke.

Acadian Pig-Iron.

	I.	II.
Carbon	3·50	3·27
Silicon	0·84	0·67
Sulphur	0·02	0·01
Phosphorus	0·19	0·28
Manganese	0·44	0·37
Iron	94·85	95·70
	99·84	100·30

I., II. These analyses were made by Mr. Tookey in my laboratory, at the request of my friend Mr. Livesey, for the Acadian Iron Company, Nova Scotia. No. I. was large in grain and highly graphitic in appearance, and No. II. was fine-grained grey pig-iron.

The ores were, I believe, micaceous red hæmatite and brown hæmatite, and the fuel was charcoal. The manganese contained a sensible amount of cobalt.

Analyses of Pig-Iron produced exclusively from Northamptonshire Ore.

	I.	II.	III.	IV.
Carbon (combined)	1·440	0·554	0·800	1·400
Carbon (graphitic)	0·610	1·150	0·754	0·304
Silicon	2·980	1·900	3·365	3·449
Sulphur	0·197	0·414	0·702	0·440
Phosphorus	0·936	1·807	1·368	1·300
Manganese	1·096	0·395	0·298	trace
Iron	92·727	93·780	92·713	93·068
	99·986	100·00	100·000	99·961
Specific gravity	7·022	..	6·973	7·078

They were made by the late Mr. T. H. Henry for Mr. S. H. Blackwell, by whom they have been communicated.

I. Grey. Made at Bilston with hot-blast. II. Described as "exceedingly tender iron." Made at Bilston with hot-blast and coke, ½ from North-Welsh coal and ½ from Bilston New Mine coal. III. White-mottled. Made at Heyford, near Weedon, with hot-blast and equal parts by weight of coal and coke. IV. Made at Wellingborough with cold-blast and coal from Yorkshire, without any coke. In Nos. II. and III. the iron was determined by difference, and in Nos. I. and

IV. by standard solution of hypermanganate of potash. No. III. contained traces of copper and arsenic.

	Per cent. I.	II.	III.
Carbon, graphitic	2·85	2·10	2·64
Silicon	1·92	2·11	4·63
Sulphur	0·10	0·13	0·07
Phosphorus	1·19	1·07	1·31
Manganese	0·24	0·08	trace

(A. W.) I. specified as No. 1 grey foundry, and II. as mottled pig, made by Messrs. Butlin and Co., East End Iron-works, Wellingborough, Northamptonshire, with cold-blast.

An analysis of the ore will be found in Table IV., No. 5.

The fuel was Barnsley coal used raw, which contained 0·65% of sulphur, and yielded 4·76% of ash, consisting of silicate of alumina, with a little sesquioxide of iron, and traces of lime and magnesia. In a crucible experiment it gave 76·36% of coke.

Two kinds of flux were employed, pale yellow argillaceous limestone, oölitic in structure, and a small proportion of chalk. The limestone was composed as under:—

Carbonate of lime	89·36
Carbonate of magnesia	0·97
Carbonate of protoxide of iron	3·38
Ferruginous clay and sand	6·00
Organic matter	trace
Water	0·43
	100·14

The chalk was of ordinary quality, consisting of carbonate of lime, with traces only of silica, alumina, sesquioxide of iron, and carbonate of magnesia.

The consumption of materials in producing 1 ton of pig-iron was stated to be the following:—

	Tons.	cwts.
Ore, not calcined	2	18
Barnsley coal	2	16
Argillaceous limestone	0	10
Chalk	0	2

(A. W.) III., specified as "pig-iron, first melting," made by Mr. J. Judkins at the Heyford Iron-works, near Weedon, Northamptonshire, but whether with hot or cold blast is not stated.

An analysis of the ore will be found in Table IV., No. 6.

The fuel was coke from the Barnsley coal of the South Yorkshire Railway Company; the coal contained 0·65% of sulphur, and the coke 0·52%; and the latter yielded 6·58% of red ash, consisting of silicate of alumina, with sesquioxide of iron, and traces of lime and magnesia.

The flux was light-coloured limestone, occurring particularly near Blisworth, and formed of an agglomeration of fossil shells; after drying at 100° C. it was composed as under:—

Carbonate of lime	96·86
Carbonate of magnesia	0·90
Carbonate of protoxide of iron	1·36
Siliceous insoluble residue	0 88
	100·00

The presence of silicon and phosphorus is readily explained by the composition of the ores, which should be specially studied in connexion with the pig-iron, of which the analysis is given above.

ANALYSES OF PIG-IRON MADE FROM NORTHAMPTONSHIRE ORE AND TAP- AND FIRE-CINDER.

These varieties of pig-iron were regarded as typical examples of very inferior quality. The analyses were made for Mr. S. H. Blackwell by the late Mr. T. H. Henry.

		I.	II.
Carbon	combined	[illegible]	4·[illegible]
	graphite	2·[illegible]	2·[illegible]
Silicon		2·[illegible]	2·[illegible]
Sulphur		0·[illegible]	0·[illegible]
Phosphorus		1·[illegible]	1·[illegible]
Manganese		[illegible]	0·[illegible]
Iron		91·[illegible]	[illegible]
Aluminium		traces	traces
Arsenic		traces	traces
		[illegible]	[illegible]

I. The charge of ore consisted of equal weights of Northamptonshire ore, roasted tap-cinder, and fine or mill-furnace cinder. II. The charge of ore consisted of $\frac{4}{11}$ of Northamptonshire ore and $\frac{7}{11}$ of roasted tap-cinder. Tap-cinder usually contains a large amount of phosphoric acid.

It is stated that the wrought iron produced from both these kinds of pig-iron was red-short, as well as cold-short. They were smelted with hot-blast, and were about what is termed No. 4 forge-pig, the usual degree of greyness preferred in South Staffordshire for puddling.

PIG-IRON MADE FROM A MIXTURE OF LAKE AND BOG IRON ORES.

Pig-iron.		Slag produced at the same time.	
Carbon	1·04	Silica	48·42
Silicon	4·77	Alumina	7·56
Sulphur	0·01	Lime	27·89
Phosphorus	0·89	Magnesia	6·48
Manganese	6·08	Protoxide of iron	4·39
Aluminium	0·97	Protoxide of manganese	6·37
Calcium	1·37	Phosphoric acid	0·02
Magnesium	0·43		
Iron	85·27		101·13
	100·83		

I have received a specimen of this pig-iron from Mr. Grill. It is dull grey and finely granular in fracture. It is the result of an experiment on the large scale made at the Finspong Iron-works, in Sweden, in 1857, and was run into a cold mould of cast iron. The charge consisted of 541 lbs. of mixed lake and bog ores, 30 lbs. of lime, 176 lbs. of pine charcoal, and 176 lbs. of English coke from Newcastle (*i. e.* 3 parts by measure of charcoal to 1 of coke). It was smelted with cold-blast at a pressure of 1 lb. per square inch. The analyses, both

of the iron and slag, were made at the Mining School in Fahlun. The amounts of aluminium, calcium, and magnesium are extraordinarily large, and the analysis requires confirmation in this respect.

Analyses of Pig-Iron made wholly or chiefly from Argillaceous Iron-Ore of the Coal-Measures.

Yorkshire.

	I.	II.	III. a.	III. b.	IV. a.	IV. b.	IV. c.
Carbon, graphitic	2·99	2·90	3·32	2·98	2·80	3·14	2·84
Silicon	0·97	1·94	1·08	1·01	1·51	1·71	1·03
Sulphur	0·05	0·04	0·06	0·03	0·06	0·07	0·04
Phosphorus	0·50	0·57	0·56	0·49	0·44	0·67	0·52

(A. W.) I. specified as grey pig-iron, II. as No. 1 pig-iron, III.*a* and III.*b* as No. 2 grey pig-iron, and IV.*a*, IV.*b*, IV.*c*, as No. 3 grey pig-iron, made at the Bowling Iron-works, Yorkshire.

	I. a.	I. b.	II.	III.	IV.
Carbon, graphitic	3·15	3·03	2·90	2·83	2·76
Silicon	2·54	2·53	2·57	2·17	1·80
Sulphur	0·06	0·07	0·05	0·05	0·04
Phosphorus	0·52	0·53	0·64	0·55	0·55
Manganese	1·14	0·85	1·12	1·00	0·61

(A. W.) I.*a*, I.*b*, specified as No. 1 pig-iron, and II., III., IV. as Nos. 2, 3, and 4 pig-iron, respectively; made by Messrs. Harding and Co. at the Beeston Manor Iron-works, near Leeds, with cold-blast.

The ore used was stated to be the Black Bed ironstone of the coal-measures of the locality. No details as to fuel or flux are given.

Derbyshire.

Per cent.	I.	II.	III.	IV.
Carbon, graphitic	3·35	2·74	2·71	2·60
Silicon	1·27	2·36	1·75	1·34
Sulphur	0·02	0·02	0·04	0·11
Phosphorus	1·09	1·21	1·15	0·75
Manganese	1·01	1·06	0·95	0·40

(A. W.) I., II., III., IV. were Nos. 1, 2, 3, 4, pig, respectively, made by Messrs. Needham and Co. at the Butterley Iron-works, near Alfreton, Derbyshire, from argillaceous iron-ore of the coal-measures, with hot-blast ranging in temperature from 500° F. to 600° F. Nos. I., II., III. were made from the Brown Rake ironstone, of which analyses will be found in Table VI., Nos. 7 and 8; and No. IV. from the Blue Rake ironstone, of which no analysis is given, the phosphoric acid only having been determined by Mr. Abel, and found to amount to 1·46%, which exceeds that in the Brown Rake ironstone by 0·64%. The ore is roasted before smelting.

The fuel was "Brand's Hard Coal," used raw; it contained 0·52% of sulphur, and yielded 2·97% of ash.

	Per cent.				
	I.	II.	III.	IV.	V.
Carbon, graphitic	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Silicon	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Sulphur	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Phosphorus	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Manganese	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

(A. W.) Nos. I., II., III. [illegible] foundry-pig, [illegible] were made [illegible] iron-works, [illegible] of which the temperature ranged from [illegible]

The charge [illegible] of Black and Grey [illegible] The ores were [illegible]

The fuel [illegible] of coke from the same coal.

The flux was [illegible] at Bull's Bridge and [illegible]

SOUTH STAFFORDSHIRE.

	Per cent.				
	I.	II.	III.	IV.	V.
Carbon, graphitic	[illegible]	[illegible]	3·12	3·08	2·41
Silicon	[illegible]	[illegible]	[illegible]	[illegible]	0·57
Sulphur	[illegible]	[illegible]	[illegible]	[illegible]	0·05
Phosphorus	0·43	[illegible]	0·44	0·31	0·29
Manganese	[illegible]	[illegible]	0·34	0·27	0·13

(A. W.) Nos. I., II. were Nos. 1 and 2 foundry-pig, respectively, No. III. grey-forge pig, No. IV. forge-pig, and No. V. strong forge-pig, made by Messrs. Grazebrook at the Netherton Iron-works, near Dudley, with cold-blast.

The ores employed were Binds, Whitestone, Gubbin, and Grains, of which analyses will be found in Table VI., Nos. 22*a*, 23*a*, 23*b*, 19*a*, 18*a*, 18*b*.

The fuel was Thick-coal coke, which contained 0·31% of sulphur, and yielded 4·18% of reddish ash, consisting of silicate of alumina, with sesquioxide of iron, lime, and a trace of magnesia.

The flux was light coloured, crystalline Silurian limestone from Dudley, of which, after drying at 100° C., the composition was as under: -

Carbonate of lime	97·31
Carbonate of magnesia	1·00
Carbonate of protoxide of iron	0·62
Clay and sand	1·27
Organic matter and water	0·20
	100·40

The following analyses of pig-iron, specified simply as cold-blast grey-pig, were also made at the Arsenal.

	Per cent.			
	VI.	VII.	VIII.	IX.
Carbon, graphitic	2·86	2·97	2·93	2·64
Silicon	1·06	1·57	1·66	1·02
Sulphur	0·08	0·07	0·04	0·08
Phosphorus	0·42	0·42	0·34	0·45

	Per cent. I.	II.	III.
Carbon, graphitic	2·89	2·90	3·00
Silicon	0·96	1·63	1·21
Sulphur	0·06	0·03	0·10
Phosphorus	0·58	0·55	0·48
Manganese	0·55	0·95	0·86

(A. W.) I., II., III. were No. 1 pig, grey-forge, and forge-pig, respectively, made by Messrs. Evers and Martin, at the Parkhead Furnaces, Dudley, with cold-blast. The analyses Nos. I., II. were made upon square bars cast for testing strength, and No. III. upon the original pig.

The charge of ore consisted of ¾ of Bottomstone and Binds, and ¼ of Gubbin and Rubble. Average samples of these (calcined) were partially analysed by Mr. Abel, and the results are as under:—

	New Mine Whitestone measures.		From the Gubbin measures.	
	Bottomstone.	Binds.	Gubbin.	Rubble.
	Per cent.		Per cent.	
Metallic iron	57·10	54·43	59·87	47·93
Phosphoric acid	0·78	0·67	0·62	0·52
Ignited insoluble residue	13·42	12·18	12·50	24·30

The fuel was Thick-coal and Heathen-coal coke. The Thick-coal coke contained 0·40 % of sulphur, and yielded 3·78 % of ash, consisting of silicate of alumina, with sesquioxide of iron and very little lime and magnesia. The Heathen-coal coke contained 0·51 % of sulphur, and yielded 4·58 % of ash, similar in composition to that of the former.

The flux was Silurian limestone from Dudley, of which, after drying at 100° C., the composition was as under:—

Carbonate of lime	97·10
Carbonate of magnesia	0·85
Carbonate of protoxide of iron	0·60
Sand and clay	1·15
Water and loss	0·30
	100·00

The following analyses of pig-iron, from No. IV. to IX. inclusive, from the Parkhead furnaces, specified simply as cold-blast grey-pig, have also been made at the Arsenal.

	Per cent. IV.	V.	VI.	VII.	VIII.	IX.
Carbon, graphitic	2·83	2·85	3·33	3·31	3·11	2·81
Silicon	1·19	0·96	1·18	1·22	1·33	1·13
Sulphur	0·08	0·08	0·05	0·05	0·07	0·05
Phosphorus	0·55	0·51	0·48	0·49	0·58	0·60

	Per cent. I.	II.
Carbon, graphitic	2·61	2·56
Silicon	1·40	1·75
Sulphur	0·04	0·05
Phosphorus	0·72	0·63
Manganese	0·49	0·06

(A. W.) No. I. was specified simply as hot-blast, and No. II. as cold-blast pig-iron, made at the Earl of Dudley's Level Iron-works,

Brierley Hill, with half mine. The analyses were made upon square bars cast for testing strength. No. I represents the average composition of four hot-blast pigs, and No. II the average of five cold-blast pigs.

The charge of ore consisted of equal parts of Bottom and Whitestone, unroasted. The raw ores were partially analysed by Mr. Abel, and the results are as under:—

	Per cent.	
	Bottom.	Whitestone.
Metallic iron	[illegible]	[illegible]
Phosphoric acid	[illegible]	[illegible]
Sulphur	not appreciable	a trace
Insoluble siliceous matter	[illegible]	[illegible]

The fuel was Thick-coal coke, which contained [illegible] of sulphur, and yielded [illegible] of red ash, consisting of silicate of alumina, with sesquioxide of iron, and traces only of lime and magnesia. The coal, it is stated, contained [illegible] of sulphur, and yielded 3·4[illegible] of ash. Either the coal or the coke could not have been average samples; for the former could not, as is reported, have contained more ash than the coke.

The flux was limestone, resembling in all its external characters that employed at the Parkhead Iron-works. It contained [illegible] of carbonate of magnesia.

		Per cent.		
	I.	II.	III.	IV.
Carbon, combined	...	...	...	0·25
Carbon, graphite	3·[illegible]	2·[illegible]	2·76	2·56
Silicon	3·4[illegible]	2·24	1·75	1·36
Sulphur	0·[illegible]	0·04	0·07	0·11
Phosphorus	0·3[illegible]	0·63	0·55	0·41
Manganese	0·30	0·34	trace	0·54

(A. W.) I., II., III., IV. were Nos. 2, 3, 4, 5 pig, respectively, made by Messrs. Badger and Co., at the Old Hill Furnace, Dudley, it is not stated whether with hot or cold blast.

The ores consisted of Whitestone, Gubbin, Grains, Pins, Balls, and Poor Robins (*vid.* Table VI.), with a small portion of Ulverstone Red Ore.

The fuel was Thick-coal coke from the Old Hill Colliery, which contained 0·51% of sulphur, and yielded 4·83% of ash, consisting of silicate of alumina, with sesquioxide of iron and a little lime.

The flux was light-coloured, crystalline limestone, from the Springfield Mine, and which, after drying at 100° C., was composed as under:—

Carbonate of lime	88·85
Carbonate of magnesia	2·03
Carbonate of protoxide of iron	1·21
Carbonate of protoxide of manganese	traces
Phosphate of lime, containing 0·12 of phosphoric acid	0·26
Quartz, with a little clay	8·15
Organic matter	traces
	100·50

Per cent.

	I.	II.	III.	IV.	V.	VI.
Carbon, graphitic...	2·72	2·87	3·05	2·85	3·34	3·21
Silicon	1·25	1·16	1·60	1·33	1·18	1·54
Sulphur	0·08	0·08	0·09	0·09	0·07	0·07
Phosphorus	0·36	..	0·30	0·41	0·55	0·23

(A. W.) I., II., III., IV., specified simply as grey pig-iron, V. as grey pig-iron (warm-blast), and VI. as grey pig-iron (cold-blast), from the Lays Iron-works, near Dudley.

North Staffordshire.

Per cent.

Carbon, graphitic..........................	2·54
Silicon	2·71
Sulphur	0·04
Phosphorus	1·07
Manganese	0·98

(A. W.) Made by Mr. W. S. Williamson, at the Goldendale Iron-works, near Stoke-upon-Trent, North Staffordshire, from Chalky Mine iron-ore, of which analyses will be found in Table VI., Nos. 49 and 49*a*. The description of pig is not specified; and the only details given are that the coal was from North Wales, and light-coloured crystalline limestone from Froghall was used, of which, after drying at 100° C., the composition was as under:—

Carbonate of lime....................................	97·89
Carbonate of magnesia	0·87
Carbonate of protoxide of iron.....................	0·48
Carbonate of protoxide of manganese............ / Phosphate of lime	traces
Siliceous sand	0·63
	99·87

South Wales.

	I.	II.	III.	IV.
Carbon...combined ...	0·04	2·95	2·84	3·08
Carbon...graphitic ...	3·10			
Silicon	2·16	1·96	1·21	2·22
Sulphur	0·11	0·28	0·46	0·09
Phosphorus	0·63	0·63	0·64	0·63
Manganese	0·50	0·23	0·14	0·33
Nickel / Cobalt....................	0·05	0·04	0·03	0·07
Iron........................	94·56	95·39	95·10	94·35
	101 15	101·48	100·42	100·77

The analyses were by Mr. E. Riley, by whom they have been communicated, with the consent of the Trustees of the Dowlais Iron-works. They were made at Dowlais, wholly from Welsh mine, without cinder or red ore.

I. No. 3 best mine-pig, from No. 5 furnace, cold-blast.

II. Mottled mine-pig, from No. 5 furnace, cold-blast.

III. White mine pig, from No. 5 furnace, cold-blast.

IV. Best mine-pig, from No. 18 furnace: there were three twyers, of which two were hot-blast, and one cold-blast.

	Per cent.			
	I.	II.	III.	IV.
Carbon, graphitic	2·92	3·49	2·64	2·88
Silicon	0·81	1·35	1·69	1·09
Sulphur................	0·05	0·07	0·08	0·08
Phosphorus	0·38	0·29	0·27	0·38
Manganese	0·53	0·28	0·66	0·65

(A. W.), I., II., III., IV., specified as No. 1 and C pig, No. 1 pig, common forge-pig, and No. 3 pig, respectively, made at the Blaenavon Iron-works, Monmouthshire, with cold-blast.

The ores were argillaceous ironstones from the coal-measures of the locality termed Black Pins, Pwll Llacca, Bottom Vein, Ball Mine, and Grey Vein, of which analyses will be found in Table VI., Nos. 59a, 59b, 59c, 58a, 59d. They were all roasted before smelting.

The fuel was coke from the Three Quarters-coal; it contained 0·74% of sulphur, and yielded 5·35% of ash, consisting of silica and alumina, with sesquioxide of iron, and a little lime.

Two varieties of limestone were used as flux, distinguished as the "rough" and "smooth;" the rough was light brown, largely crystalline in structure, and contained numerous fossil shells; and the smooth was pale in colour and oölitic in structure. After drying at 100° C., they were composed as under:—

	Rough.	Smooth.
Carbonate of lime	98·55	99·26
Carbonate of magnesia	0·54	0·63
Carbonate of protoxide of iron	0·50	0·33
Phosphate of lime	0 03	0·02
Siliceous sand	0·73	0·27
	100·35	100·51

The following analyses of Blaenavon pig-iron have also been made at the Arsenal:—

	Per cent.		
	V.	VI.	VII.
Carbon, graphitic	...	3·06	3·19
Silicon	1·50	1·25	1·71
Sulphur	0·06	0·07	0·04
Phosphorus	0·32	0·28	0·33

All specified simply as cold-blast grey pig-iron.

	I.	II.
Carbon	2·25	2·37
Silicium	1·14	1·09
Sulphur..............................	0·77	0·73
Phosphorus	0·82	0·76
Manganese	0·17	0·22
Iron	95·87	95·58
	101·02	100·75

Analysis of best common white forge-pig (Wales). Sample I. cast in chills; Sample II. in sand. Analysed to see if there were any chemical difference (Blaenavon Iron-works).

It was sent as two different samples, and it was only after the analyses were completed that the above information was given. This pig may be considered as best Welsh common forge-pig, made with

red ore, cinders, and Welsh mine. It worked to a good yield, and made good rails or common bars.

	Per cent. I.	II.	III.
Carbon, graphitic	2·42	2·53	2·68
Silicon	1·46	1·23	1·35
Sulphur	0·12	0·08	0·09
Phosphorus	0 32	0·46	0·50
Manganese	0·42	0·42	0·45

(A. W.) I., II., III. specified as cold-blast grey pig-iron, made at the Pontypool Iron-works, Monmouthshire.

The ore was argillaceous ironstone from the coal measures of the locality, but the particular measures are not stated; it was roasted before smelting, and a specimen of the roasted ore contained 56·83% of metallic iron, 0·73% of phosphoric acid, and 9·60% of ignited insoluble matter.

The fuel was coke, which contained 0·76% of sulphur, and yielded 12·15% of ash, consisting chiefly of lime, but containing also sand, silicate of alumina, and sesquioxide of iron in smaller proportion.

	Per cent. I.	II.	III.	IV.	V.	VI.
Carbon, graphitic	3·27	2·92	2·61	3·17	2·55	3·16
Silicon	1·87	1·73	1·71	1·58	2·07	1·55
Sulphur	0·05	0·06	0·05	0·05	0·09	0·06
Phosphorus	0·41	0.29	0·38	0·42	0·38	0·27
Manganese	0·27	0·39	0·27	0·32	0·14	0·43

(A. W.) I., II., III. specified as Nos. 1, 2, and 3, respectively, anthracite pig-iron, second melting, and IV., V., VI. as Nos. 1, 2, and 3, respectively, of the same pig-iron, first melted, made by Mr. James Palmer Budd, at the Ystalyfera Iron-works, near Swansea, with hot-blast.

The ores consisted of argillaceous ironstones from the coal-measures in the locality, termed Caus-y-glo or Cheese Mine, and Pinmelyn Mine or Yellow Pin, and red hæmatite from Ulverstone. The hæmatite forwarded to Mr. Abel as a specimen was the variety known as Kidney-ore. It was nearly pure sesquioxide of iron, the only impurities being a little oxide of manganese and silica; it contained no sulphur, and only a trace of phosphoric acid. Analyses of the other ores will be found in Table VI.

The fuel was the anthracite of the locality, from the Little Vein, which contained 0·7% of sulphur, and yielded 9·14% of white ash, consisting of silicate of alumina, with a small quantity of lime, and a trace of sesquioxide of iron.

The flux was light-coloured, crystalline limestone, which, after drying at 100° C., was composed as under:—

Carbonate of lime	99 49
Carbonate of protoxide of iron	0·18
Carbonate of protoxide of manganese	0·07
Phosphate of lime Alumina	traces
Siliceous sand	0·26
Carbonaceous matter	traces
	100·00

No traces of magnesia, of sulphates, or of heavy metals were discoverable in a large quantity of the limestone.

ANALYSES OF PIG-IRON MADE FROM CLEVELAND ORE.

	Per cent. I.	Per cent. II.
Carbon, graphitic	3·44	3·04
Silicon	1·13	2·73
Sulphur	0·03	0·04
Phosphorus	1·24	1·30
Manganese	0·43	0·38

I., II. (A. W.) were No. 2 foundry-pig, made at South Bank Furnaces, of Messrs. Samuelson and Co., Middlesboro'-on-Tees. No. I. was described as toughened pig-iron, smelted with coke prepared according to Calvert's salt process, and as run from the blast-furnace, and No. II. as ordinary foundry pig. Hot-blast was, I believe, employed.

An analysis of the ore will be found in Table VII., No. 2.

The fuel was hard, lustrous coke. In the same as examined was found imbedded a small nodule of sulphide of iron, derived from pyrites in the coal. An average sample contained 1·05% of sulphur, and yielded 5·03% of light-red ash, consisting of silicate of alumina and sesquioxide of iron, with small quantities of lime and magnesia, but not containing any appreciable amount of phosphoric acid. The large proportion of sulphur in the coke is worthy of note, and is not a satisfactory indication of the efficacy of Mr. Calvert's desulphurizing process.

The flux was dark-grey, crystalline limestone, of which the composition was as under :—

Carbonate of lime	83·65
Carbonate of magnesia	13·43
Carbonate of protoxide of iron	1·71
Carbonate of protoxide of manganese } Phosphate of lime }	traces
Sand and clay	0·64
Carbonaceous matter	0·39
Water and loss	0·18
	100·00

	Per cent. I.	Per cent. II.
Carbon, graphitic	3·35	3·31
Silicon	1·57	1·43
Sulphur	0·04	0·03
Phosphorus	1·38	1·36
Manganese	0·07	0·06

I., II. (A. W.) were Nos. 1 and 3 pig, respectively, made by Messrs. Holdsworth, Bennington, and Byers, Stockton-on-Tees, from Cleveland ore and a little hæmatite, with hot-blast.

The ore was from the Belmont Mines, and an analysis of it will be found in Table VII., No. 3.

The fuel was coke, which contained 0·91% of sulphur, and yielded 7·90% of ash, consisting of burnt shale with a little sand, and, therefore, of silica, alumina, sesquioxide of iron, and a little lime.

The flux was dark-grey, crystalline limestone, from the Broadwood Quarries. Its composition, after drying at 100° C., was as under :—

Carbonate of lime	95·92
Carbonate of magnesia	1·85
Carbonate of protoxide of iron	0·53
Carbonate of protoxide of manganese	traces
Siliceous matter	1·70
Organic matter	traces
	100·00

ANALYSES OF TITANIFEROUS PIG-IRON.

My friend, Mr. Riley, has communicated to me the following analyses by himself of pig-irons which have special points of interest :—

No. I. made with red hæmatite and $7\frac{1}{2}\%$ of Ilmenite. Pig No. I., best foundry, found to be practically very strong iron, and answered well for the Bessemer process. No. II., not best foundry. No. III., grey pig. These two samples of pig were made with red hæmatite mixed with a little Belfast aluminous ore : the effect of the latter on the working of the furnace was stated to be very beneficial.

	I.	II.	III.
Carbon	3·31	3·18	3·11
Silicium	1·86	3·28	3·55
Sulphur	0·071	0·058	0·112
Phosphorus	0·076	0·062	0·093
Titanium	1·150	0·71	0·470
Manganese	0·50	0·48	1·09
Iron	93·47	92·79	92·04
	100·437	100·560	100·465

In the determination of the graphite by the ordinary method the following amount of fixed matter was found with it, which proved to be nearly all titanic acid.

Grs. of Pig taken.	Gave graphite and titanic acid.	After burning residue.	Titanic acid determined in residue.
1.—205·68	7·82	1·23	1·085
2.—207·05	7·85	0·835	0·745
3.—218·86	7·04	0·830	0·280

The titanic acid was determined by fusing the residue with bisulphate of potash; dissolving in cold water, and boiling; collecting the precipitate ; washing with dilute sulphuric acid, drying, and igniting.

Titaniferous Iron Ore used (Ilmenite) for Sample No. I. (Pig).

Magnetic oxide of iron	46·14	54·72
Titanic acid	36·88	40·80
Silica	13·32	1·58
Magnesia	2·07	2·13
Lime	0·78	0·66
Bisulphide of iron	1·05	—
	100·24	99·89

Analyses of Pig-Iron made with Manganiferous Cornish Ores, to determine what amount of Manganese could be alloyed with the Iron in the Blast-Furnace.

	I.	II.	III.
Graphite	3·12	3·010	2·615
Combined carbon	0·310	1·030	0·074
Silicon	2·59	2·350	3·325
Sulphur	0·035	0·035	0·017
Phosphorus	0·147	0·154	0·201
Nickel and cobalt	0·070	0·110	—
Copper, with a little antimony	0·090	0·045	0·064
Titanium	0·790	1·150	1·629
Manganese	5·850	6·370	8·087
Iron	87·90	86·880	84·256
	100·653	100·315	100·268

Nos. I. and II. ½ Cornish ore, ¼ red hæmatite, ¼ Irish bog-ore, containing 6 to 9% of manganese. Pig not foundry, but contained small patches of bright-iron: both samples were drilled, but the iron was rather hard.

No. III. ¾ Cornish ore, ¼ Irish bog ore. Pig not homogeneous, containing some No. 1, and Nos. 3 and 4: it was too hard to drill, and had somewhat the appearance of "glazed" pig.

CHARGES AND YIELDS OF BLAST-FURNACES.

Example of an average Charge at the Newland Furnace, near Ulverstone, Cumberland.[1]

			lbs.
Red hæmatite from		Whiteriggs	60
Do.	do.	Lindale Moor	280
Do.	do.	Gillbrow	50
			390
Argillaceous iron ore			25
Charcoal, about			400

The furnace will take about 16 charges on the average in 12 hours, *i. e.* between cast and cast; and the average yield of grey pig-iron per 16 charges is 1 ton 12 cwts. 2 qrs., of 2400 lbs. to the ton.

The proprietors of this furnace, Messrs. Harrison, Ainslie, and Co., have three other furnaces working with charcoal, viz. one at Backbarrow in Lancashire, another at Duddon in Cumberland, and the third at Lorn in Argyleshire, Scotland.[2] The dimensions of these furnaces are about as follow:—3 ft. in diameter at the mouth, 9 ft. in diameter at the top, 2 ft. at the bottom of the boshes. They are all worked with cold-blast urged by water-power. The average weekly make of each furnace is 20 tons, of 2400 lbs. to the ton. The varieties of pig-

[1] For the details of charges I am indebted to my former pupil, Mr. R. S. Roper, son of Mr. Thomas Roper.

[2] For this and the following details I am indebted to Mr. Thomas Roper, Newland Furnace, near Ulverstone, Aug. 17, 1863.

iron produced are known in the market by the names of open-grey, close-grey, mottled and white Lorn iron, and kishy grey forge-pig. The foundry iron is in great request for malleable castings, which are prepared from the metal melted in crucibles.

The usual market price of this pig-iron is from 8*l.* to 9*l.* per ton, while charcoal pig-iron of high quality may be imported from Sweden at about 6*l.* per ton. The Persberg pig-iron, for example, I know, may now be purchased in Hull at that price. Our own charcoal pig-iron has the advantage of a long established reputation; but whether it is really superior in any respect to such pig-iron as that of Persberg I do not know.

Charges at Finspong, in Sweden, for Pig-Iron suitable for Cannon.

At the well-known iron-works at Finspong, Ostgothland, in Sweden, belonging to my friend Mr. C. Ekman, of Norrköping, the pig-iron intended for cannon is run direct from the furnace into moulds, whereas it is usual in other gun-foundries previously to remelt the pig-iron in reverberatory furnaces. In 1857 the charge was composed as follows:[3]—

	Lispunds.	Lispunds.	Lbs. avoird.
Ferola ores	29·8	42·0[4]	625·80
Jerna do.	5·4		
Petäng do.	4·1		
Stenbo do.	2·7		
Small scrap pig-iron (Brucheisen)		1·5	22·35
Borings		1·5	22·35
Limestone		6·5	96·85
		51·5	767·35
		Tunnas.	Imperial bushels.
Charcoal		9	36

The Ferola ores are stated to be very characteristic on account of their coarsely-granular crystalline texture, and consist chiefly of magnetite and quartz in coarse grains, with some oligoclase (*i.e.* soda-felspar), amphibole, and iron-pyrites. The Jerna ore is a richer, less compact magnetite, with some quartz, oligoclase, and amphibole.[5] The Petäng ores are similar to those of Ferola, except that they are not so coarsely granular, and are very rich in manganese. The Stenbo ore is a mixture of magnetite and specular iron ore. Tunner remarks that in external appearance these ores, especially those of Ferola, offer a complete contrast to the Dannemora ores, and are only very slightly roasted.

The ores yield from 48% to 52% of pig-iron, of great strength, and well adapted for cannon. It is free from phosphorus, but contains a notable quantity of sulphur; and this is a point deserving attention.

[3] Tunner, Eisenhüttenwesen in Schweden, p. 16.

[4] 1 lispund = 14·9 lbs. avoird.

[5] In the Ferola ores Tunner designates this mineral as amphibole, and in these ores as hornblende.

The sulphur, so far from impairing, is believed to increase, the strength of the metal.

I have received from Mr. C. Ekman six sample specimens of this pig-iron, representing the transition from grey to nearly white iron. They are in cylindrical pieces turned on a lathe to a certain depth, and then broken across to show fracture. I have photographs of them, giving an accurate notion of their structure, which it would be hopeless to attempt to indicate by wood-engraving. The grey varieties, which are those adapted for gun-founding, have a characteristic fracture, to which I have previously adverted when considering the action of sulphur upon molten cast-iron. It consists essentially of a delicate white network of white-iron, the meshes being more or less circular, and filled with grey-iron. By melting grey pig-iron, so that it may take up a certain proportion of sulphur, a product is readily obtained which presents identically the same appearance on fracture. I have also noticed this fracture in cast-iron run from a cupola at Oldbury, South Staffordshire. I have particularly interrogated the intelligent managers of iron-works from every part of England as to their opinion concerning the influence of sulphur, in certain proportions, even on bar-iron; and they have, without an exception, expressed the opinion that it is not unfavourable to strength, however it may interfere with the finish on the surface of the metal.

Example of Charge and Yield at one of the Russell's Hall Furnaces, near Dudley, Dec. 27, 1851.[6]

		Cwts.[7]	qrs.	lbs.
Ores...	Red-mine, roasted, North Staffordshire	4	1	4
	Gubbin do. South Staffordshire	2	0	16
	Whitestone do. do. do.	15	0	0
	Balls do. do. do.	6	1	20
	Tap and flue cinders	2	0	16
	Total iron-producing materials	30	0	0
Limestone, Silurian, from the "Wren's Nest," near Dudley		9	0	0
Fuel...	Coke	16	0	0
	Raw coal	2	1	0
	Total fuel	18	1	0

Yield of pig-iron 14½ cwts. of 120 lbs. to the cwt.

Hot-blast was employed at a pressure of about 3½ lbs. to the square inch, and at a temperature of about 600° F. Analyses of the ores will be found in the tables previously inserted. I was present when the furnace was tapped while working on these charges. The pig-iron was grey; and at the same tapping three varieties in greyness were obtained, according as the metal flowed from different parts of the hearth.

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[6] For these details I am indebted to the proprietor, my friend, Mr. S. H. Blackwell.

[7] Cwts. of 120 lbs. to the cwt. All the charges and yields are given in the form in which I received them, in order that the methods of keeping yield accounts at various works may be seen.

WEEKLY MAKE OF NOS. 5 AND 6 FURNACES AT CORNGREAVES, BELONGING TO THE NEW BRITISH IRON COMPANY.[8]

1862.		No. 5.	No. 6.
		Tons.	Tons.
Week ending Jan.	4th	230½	239½
,, ,,	11th	217½	225
,, ,,	18th	223½	203
,, ,,	25th	230½	202½
,, Feb.	1st	142½	230½
,, ,,	8th	207½	225
,, ,,	15th	236	241½
,, ,,	22nd	240½	233
,, March	1st	250½	234
,, ,,	8th	248½	241
,, ,,	15th	160	241½
,, ,,	22nd	219	224
,, ,,	29th	230	213½
,, April	5th	237	236
,, ,,	12th	251	243½
,, ,,	19th	260	255½
	Total	3584½	3689

	Tons.	cwts.	qrs.	lbs.	Tons.	cwts.	qrs	lbs.
Average per week	224	0	2	14	230	11	1	0

It is one of these furnaces which has been minutely described and copiously illustrated. All the pig-iron was grey.

EXAMPLE OF CHARGES AND YIELDS AT NO. 12 FURNACE, DOWLAIS IRON-WORKS.[9]

1863.	Ores. Welsh Mine.	Ores. Red Ore.	Ores. Forest Ore.	Consumption of coal per ton of pig-iron.			Total make.		
	Tons.	Tons.	Tons.	cwts.	qrs.	lbs.	Tons.	cwts.	qrs.
Week ending 23rd May	166	327	..	23	1	1	213	7	0
,, 30th ,,	168	293	..	26	1	29	180	4	0
,, 6th June	177	317	..	26	1	28	181	1	0
,, 13th ,,	169	308	..	23	0	15	190	12	0
,, 20th ,,	181	267	4	25	3	26	161	18	2
,, 27th ,,	303	176	48	27	0	0	186	8	1
,, 4th July	251	146	53	27	0	21	164	16	2
,, 11th ,,	265	122	80	25	2	3	171	18	1
,, 18th ,,	287	111	100	27	0	9	191	3	1

Welsh-mine means argillaceous iron-ore from the coal-measures, red ore means red hæmatite, and Forest-ore brown hæmatite from the Forest of Dean. The pig-iron made during the period indicated in the preceding statement was No. 2 and No. 3 grey, and was very uniform in quality. The tons specified are of 2400 lbs. avoird. to the ton. In varying the charges, the fuel is constant, except in extreme cases.

[8] I am indebted for these details to the former manager, my friend, Mr. J. K. Blackwell. I have not received any account of the charges.

[9] I am indebted for these details to my friend, Mr. William Menelaus, the manager, July 25, 1863.

Example of Charges and Yields at the Aberdare and Abernant Furnaces.

Pig-Iron, etc., made Week ending 27th June, 1863.

	Quality.	2240 lbs. Imperial Weight
Aberdare, No. 1	White	249
„ „ 2	„	272
„ „ 3	„	208
Abernant „ 1	„	297
„ „ 2	„	327
Tons	...	1353

Charge for 1 Ton of Pig-iron.

	Iron-producing materials.									Lime.			Coal.								
													Furnaces.			Hot-blast Engines.			Total.		
	cwt.	qr.	lb.	cwt.	qr.	lb.	cwt.	qr.	lb.	cwt.	qr.	lb.	cwt.	qr.	lb.	cwt.	qr.	lb.	cwt.	qr.	lb.
Aberdare, No. 1...	6	1	0	20	0	17	17	0	22	7	3	7	36	0	5						
„ „ 2...	15	0	0	13	2	19	16	0	4	8	2	20	37	1	15	1	1	12	40	1	8
„ „ 3...	34	3	17	...			13	2	8	10	2	19	44	2	4						
Abernant „ 1...	6	0	5	21	0	18	15	3	20	7	2	7	34	2	23	0	0	17	36	1	2
„ „ 2...	6	2	17	20	1	0	18	0	0	8	1	6	38	0	8						
Average charges	12	1	24	15	2	0	16	2	5	8	1	27	37	3	7	0	3	5	38	2	12

Pig-Iron, etc., made Week ending 4th July, 1863.

	Quality.	2240 lbs. Imperial Weight.
Aberdare, No. 1	White	287
„ „ 2	„	300
„ „ 3	„	214
Abernant „ 1	„	287
„ „ 2	„	343
Tons	...	1431

Charge for 1 Ton of Pig-iron.

	Iron-producing materials.									Lime.			Coal.								
													Furnaces.			Hot-blast Engines.			Total.		
	cwt	qr.	lb.	cwt.	qr.	lb.	cwt.	qr.	lb.	cwt.	qr.	lb.	cwt.	qr.	lb.	cwt.	qr.	lb.	cwt.	qr.	lb.
Aberdare, No. 1...	6	1	1	20	1	25	17	0	25	7	3	8	36	0	15						
„ „ 2...	6	1	15	20	2	1	17	1	11	7	3	16	36	1	14	1	1	25	39	0	10
„ „ 3...	32	2	8	...			14	1	18	9	3	16	41	1	14						
Abernant „ 1...	6	0	25	21	2	27	17	0	8	7	3	1	35	2	17	0	0	17	36	2	22
„ „ 2...	6	2	2	20	3	3	17	3	18	8	0	14	37	1	6						
Average charges	9	3	24	16	2	23	16	3	0	8	0	24	37	0	17	0	3	16	38	0	3

Pig-Iron, etc., made Week ending 25th July, 1863.

	Quality.	2240 lbs. Imperial Weight.
Aberdare, No. 1	White	278
" " 2	"	285
" " 3	"	253
Abernant " 1	"	281
" " 2	"	329
Tons	...	1426

Charge for 1 Ton of Pig-iron.

	Iron-producing materials.									Lime.			Coal.								
													Furnaces.			Hot-blast Engines.			Total.		
	cwt.	qr.	lb.	cwt.	qr.	lb.	cwt.	qr.	lb.	cwt.	qr.	lb.	cwt.	qr.	lb.	cwt.	qr.	lb.	cwt.	qr.	lb.
Aberdare, No. 1...	6	1	21	20	2	0	17	2	20	8	0	0	36	3	24						
" " 2...	6	1	15	20	1	11	17	2	7	8	2	27	36	2	23	1	0	14	39	0	0
" " 3...	32	1	19	...			14	0	3	9	2	22	40	0	25						
Abernant " 1...	6	1	27	20	2	21	17	3	8	8	0	12	37	1	2	0	2	19	37	3	13
" " 2...	6	1	26	20	2	18	17	3	5	8	0	10	37	0	19						
Average charges	10	3	26	16	2	5	17	0	6	8	1	10	37	2	10	0	3	20	38	2	1

Charges and Yields of "Old Blast Furnace," Blaenavon Iron-works.—"Cold-Blast."[1]

The charge for upwards of ten years has been—

Calcined native mine	10	cwts.
Limestone	3½	"
Coke*	7	"

* The coke being composed of ¾ Old coal and ¼ Three-quarter coal.

36 charges pass through furnace in 48 hours.

The "charge" has been, per ton, of iron made—

	Tons.	cwts.	qrs.	lbs.
Raw mine....................	3	11	0	20
Limestone....................	1	0	3	5
Coal	2	14	2	17

The average *make* per week of mine-iron for the last ten years has been 104½ tons, in the following proportions on the average:—

No. 1	14·08 tons.
No. 2	6·55 "
No. 3	16·86 "
Grey forge....................	18·61 "
Common forge	30·88 "
Forge	2·18 "
Bright	1·36 "
Mottled	1·50 "
Castings....................	3·61 "

50,000,000 cubic ft. of cold-blast air are consumed weekly in the production of the 104·08 tons of iron. The pressure of blast from 2¼ lbs. to 3 lbs. per square inch.

[1] I am indebted to Mr. Finch for these details, Dec. 1863.

Example of Charge in No. 2 Blast-furnace at the Cwm Celyn Iron-works, Monmouthshire.

		Number of barrows.	Cwts.
Welsh mine, calcined (1 barrow = 8 cwts.)		10	80
Brown hæmatite from Llantrissant (1 barrow = 8 cwts.)		3	24
Forge, mill, and refinery cinders, part raw, and part roasted	1 barrow = 8 cwts.	5	40
Iron-yielding materials		18	144
Coal, mixed (1 barrow = 10 cwts.)		3	30
Coke (1 barrow = 7 cwts.)		5	35
		8	65
Limestone		..	2

The calculation is made by barrows. Eight barrows of coal and coke mixed are the unit of measure, and the proportions in which they are mixed are expressed by the fraction $\frac{3}{5}$, the numerator indicating coal, and the denominator coke. Thus the proportion of ore is estimated in relation to 8 barrows of fuel.

			Tons[1]	cwts.	qrs.	lbs.
The pig-iron made in two furnaces at Cwm Celyn during the year ending March, 1857			22.114	7	0	0
The mean yield per furnace per week about			212	0	0	0
Welsh mine, raw	per ton of pig-iron		1	17	2	12
Hæmatite	do.	do.	0	7	3	28
Forge, mill, and refinery cinders	do.	do.	0	11	2	9
Total iron-yielding materials	do.	do.	2	17	1	9
Limestone	do.	do.	0	3	2	13
Total coal (inclusive of that from which the coke was produced)	do.	do.	1	2	3	0

The furnaces were worked with hot-blast heated in gas-ovens. The steam of the blowing engine was also heated by the waste gas of the blast-furnaces. The mine was calcined with coal scraped from the roads. Mr. Levick, one of the proprietors, informs me that the make of this year was quite exceptional with regard to the smallness of the quantity of coal used; and Mr. James, the blast-furnace manager, states that this is the greatest reduction of coal he had ever succeeded in effecting for 1 ton of pig-iron made.

Example of Charge for Foundry Iron at the Clarence Iron-works, near Middlesboro'-on-Tees, belonging to Mr. I. Lowthian Bell.[2]

	Cwts.	qrs.		Cwts.	qrs.
Cleveland iron ore	8	0	to	8	1
Limestone	2	2	to	2	3
Coke	6	0		..	

A description of one of the furnaces at these works has been previously given. The yield of the Cleveland ore varies from 27% to 32% of pig-iron.

[1] Long tons of 2400 lbs. to the ton. The coal is calculated by the ton of 21 cwts. of 120 lbs. to the cwt.; *i.e.*, of 2520 lbs. to the ton.

[2] I am indebted to Mr. Bell for this information, received Oct. 29, 1859.

Illustrations showing Variations in the form of Blast-furnaces.

The numbers in cubic feet at the bottom indicate the solid contents, and have been all calculated by Mr. Pole.

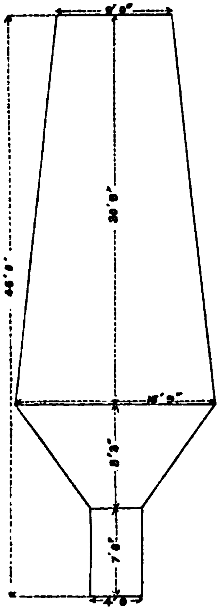


Fig. 85. Mushet on Iron and Steel. 4560 cub. ft.

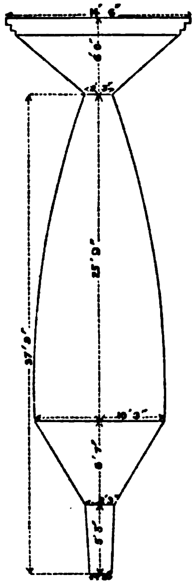


Fig. 86. Mushet on Iron and Steel. 1900 cub. ft.

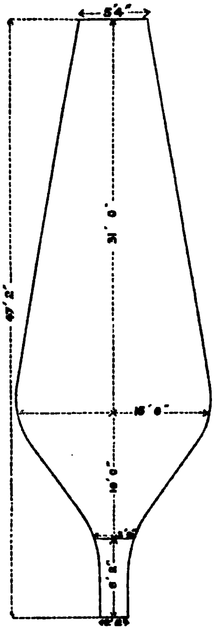


Fig. 87. French. 3700 cub. ft.

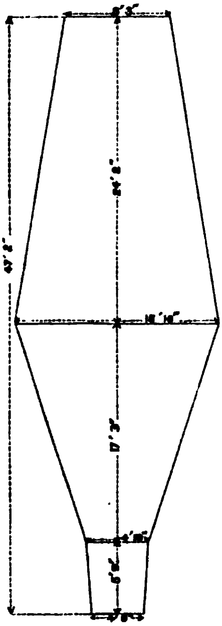


Fig. 88. Nithsdale, Scotland. 4540 cub. ft.

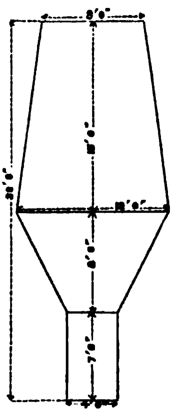


Fig. 89. Watney's Anthracite furnace, South Wales. 1720 cub. ft.

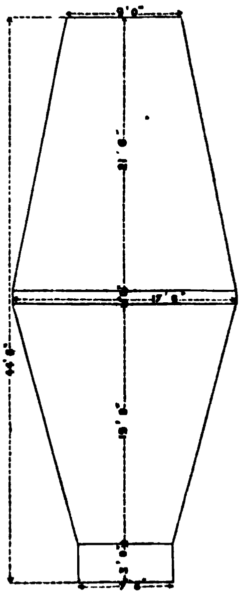


Fig. 90. No. 3, Ebbw Vale, South Wales. 5890 cub. ft.

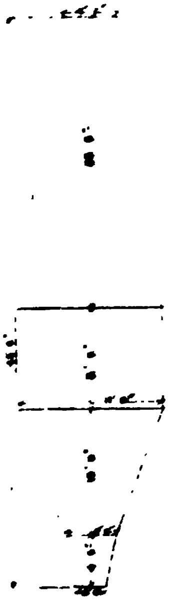


Fig. 91. Madeley Wood, Shropshire. 2600 cub. ft.

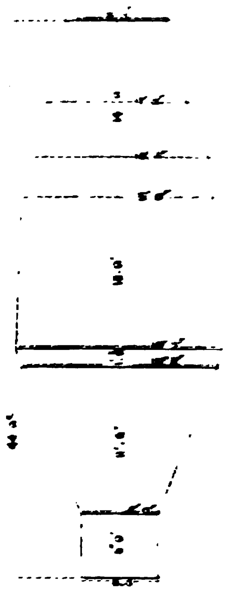


Fig. 92. Glengarnock, Scotland. 5270 cub. ft.

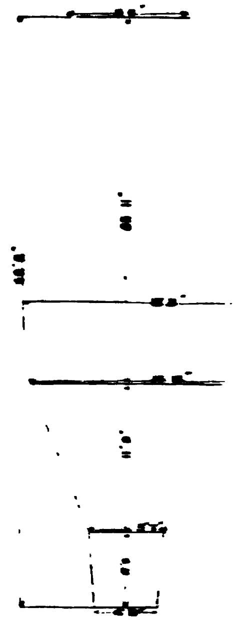


Fig. 93. No. 1, Blaenavon, South Wales. 5840 cub. ft. The charges and yields of this furnace have been given.

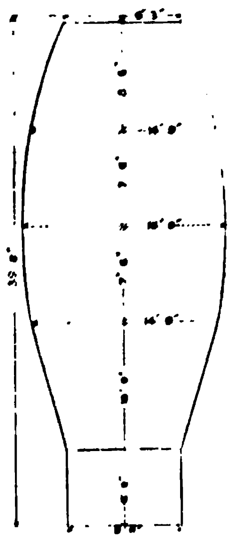


Fig. 94. Russell's Hall, South Staffordshire. 5280 cub. ft.

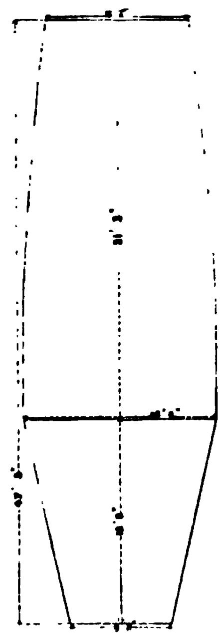


Fig. 95. Ruabon, North Wales. J. K. Blackwell, 1859. 6400 cub. ft.

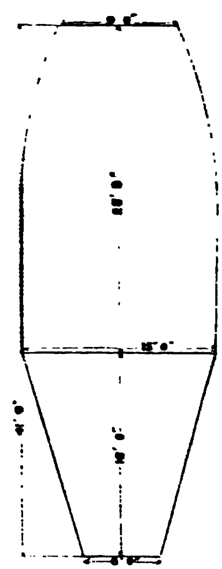
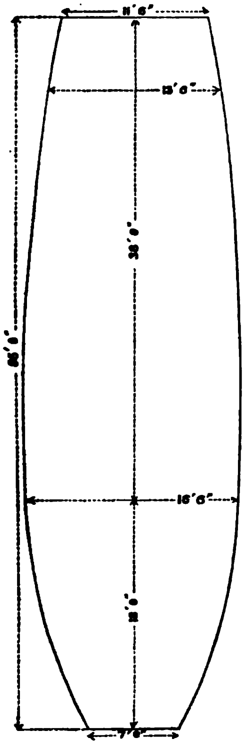
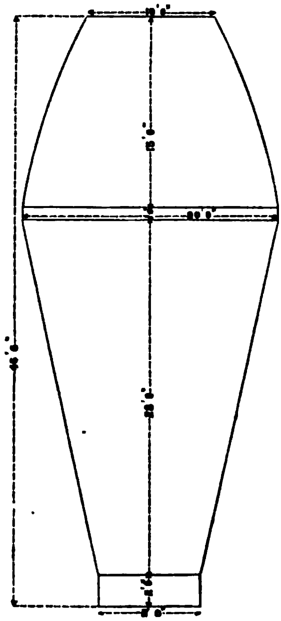


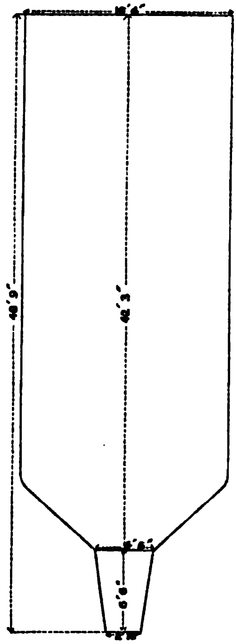
Fig. 96. No. 2, Cwm Celyn, South Wales. 5360 cub. ft. This furnace produced a weekly average of 209 tons of white-iron during 52 consecutive weeks.



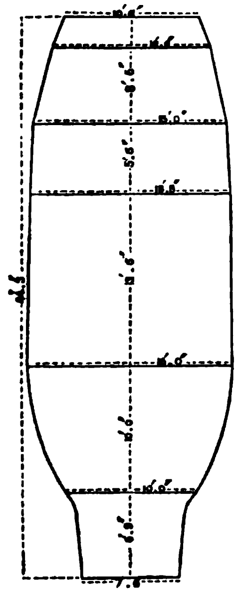
97. Schneider, Hannay, and Co.,
Barrow-in-Furness, Lancashire.
9300 cub. ft.



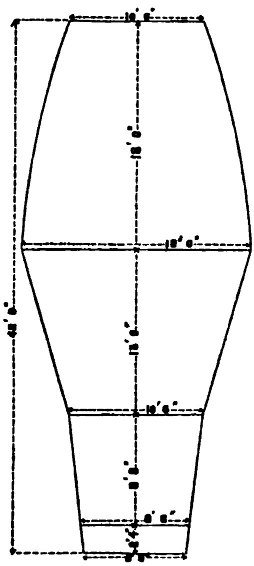
98. No. 17, Ebbw Vale.
8000 cub. ft.



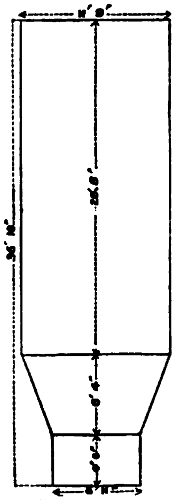
99. An old furnace at Dowlais.
Copied from Karsten's Atlas,
fig. 618, published 1831.
8220 cub. ft.



100. Ruabon, N. Wales.
6650 cub. ft.

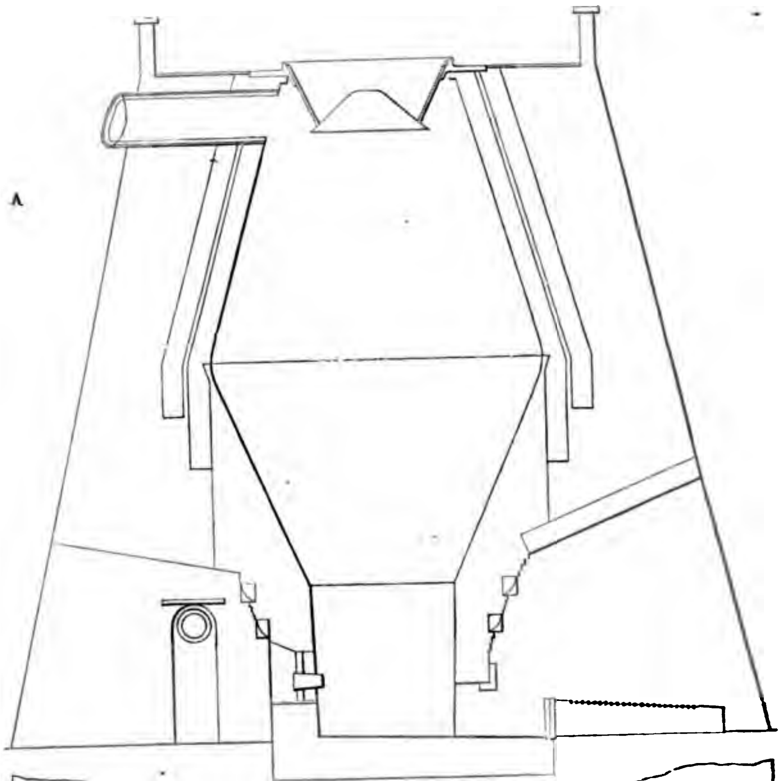


101. No. 12, Dowlais. 1863.
6160 cub. ft.



102. Muirkirk, Scotland.
3440 cub. ft.

A



B

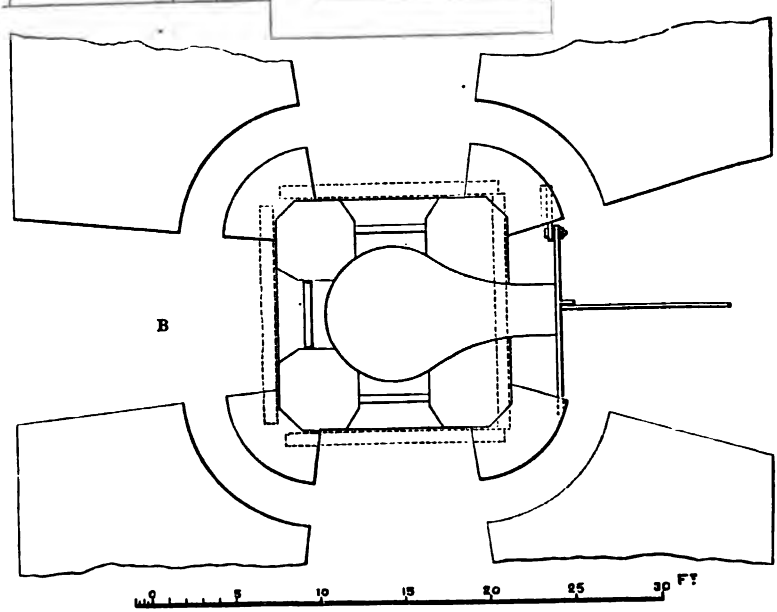
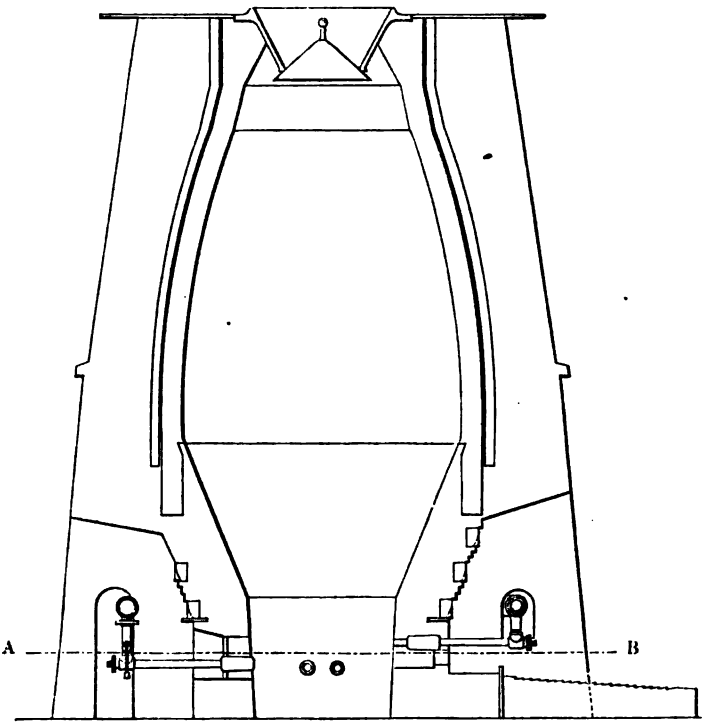
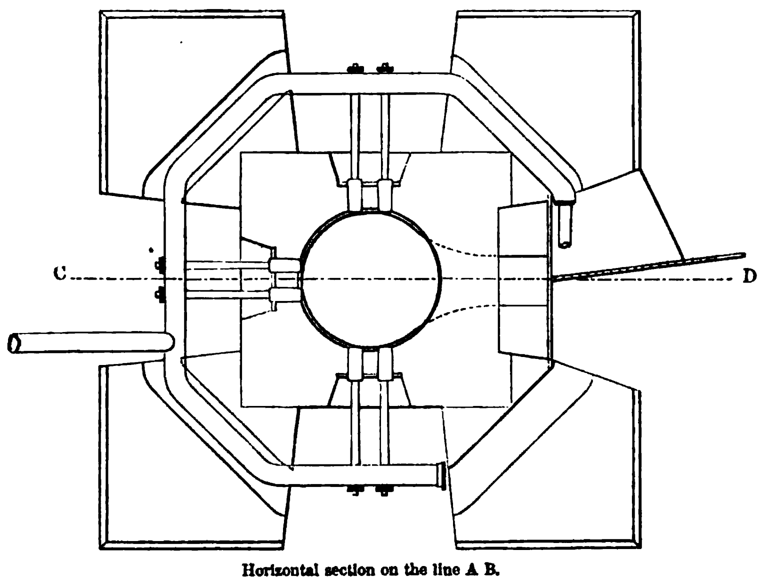


Fig. 103. No. 2 Furnace, Abernant.
A. Vertical section through the centre of the mouth from back to front. B. Ground plan.



Vertical section on the line C D.



Horizontal section on the line A B.

Fig. 104. No. 1 Furnace, Aberdare. I am indebted to Mr. William Menelaus, of Dowlais, for the drawings from which figs. 103, 104 have been executed. The charges and yields of these furnaces have been given

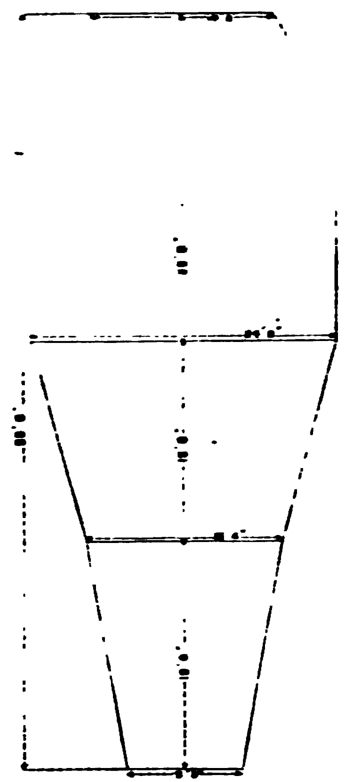


Fig. 105. No. 3, Cwm Celyn. Not completed. 16,560 cub. ft.

DIMENSIONS, CHARGES, AND YIELDS OF THE BLAST-FURNACES OF PRUSSIA.[4]

I am indebted to Dr. Hermann Wedding, of Bonn, for the following compendious account of the dimensions, charges, and yields of the blast-furnaces of Prussia, which cannot fail to interest the British iron-master.

Prussia is rich in iron-ores, but they seldom occur along with the coal. In former times, the blast-furnaces were built where wood abounded and water-power was available; but in later times, as the use of coal and coke became more and more general, it was found that the coal-basins were the fittest localities for the erection of works, as it was more easy and economical to take the ore to the fuel than the fuel to the ore.

I. *Eastern Provinces.*—1. *Upper Silesia.*—The ores of Upper Silesia are partly brown iron-ores, which occur near the surface on the Muschelkalk limestone, which covers the coal-measures; partly clay ironstone, as balls and bands in the coal-measures themselves. These are the foundation of the very important iron industry of the Upper Silesian coal-basin. In the north, in the districts of Rosenberg, Kreuz-

[4] The numbers are nearly all from official sources, and refer, if not otherwise stated, to the year 1861.

burg, and Lublinitz, as south in the districts of Gleiwitz, Rybnik, and Ratibor, occur clay ironstones (sphærosiderites) in the oölite and tertiary formations, and these supply the charcoal-furnaces of Upper Silesia. The clay ironstones are brought also in certain quantities to the coke-furnaces, and the brown iron-ores from the Muschelkalk-formation to the charcoal-furnaces.

A. *The coke blast-furnaces of Upper Silesia.*—These blast-furnaces, which are situated on or very near the coal-measures, are partly worked by the Government (fiscus), and partly by private individuals.

After the Prussian occupation of Silesia, Frederic the Great ordered a certain Mr. Rhedanz, a high official connected with the direction of forests, to look out for fit places for iron-works; so that by the development of the iron industry in this then poor and thickly-wooded land the inhabitants might be better supported than was possible by purely agricultural pursuits. Malapane, three miles south-west of the town of Oppeln, on the banks of a river of the same name, was selected, because of its great richness in superficial bog-ores. In 1753 the building of the first furnace began, and in 1754 it was blown in. Soon better ores in the Oölite were found not far away, and the woods furnished plenty of fuel. The erection of another Royal and many private furnaces quickly followed. In 1780, Reden, subsequently Oberberghauptmann and minister, was appointed Mining Director of Silesia. He made a long journey through England, particularly to inform himself as to the use of coal and coke in the smelting and manufacture of iron. He ordered trials with coke to be made at Malapane (the first was in 1789), and finding success, he instructed Mr. Wedding, grandfather of the author, at that time building-inspector, and Mr. Bogatsch, Royal assessor, to present plans for a large coke-work at Gleiwitz. This done. the building was commenced under Mr. Wedding's personal direction in 1794. In 1796 this blast-furnace—the *first* coke blast-furnace on *the whole continent* of Europe—was in blast.

Two years later a still larger Royal work, Königshütte, was begun and executed by Mr. Wedding, and a Scotchman, Mr. J. Baildon (engaged by the above-named Mr. Reden), who, in 1805, built an iron-work on his own account. The first two furnaces of Königshütte were blown in in 1802. From that period dates the rapid progress of the iron industry of Upper Silesia.

There are two Government works, viz. the above-named Gleiwitz and Königshütte. Gleiwitz has now two blast-furnaces. The ores are brown iron-ore of 25 % produce, clay ironstone of 40 %, and balling furnace-cinder of 50 %, inclusive of cast-iron scrap.

Ctr.			Ctrs.	
For 1 of pig iron	were	required	3·25	iron-producing materials (ore and cinder).
,,	,,	,,	0·98	limestone.
,,	,,	,,	2·64	coke.

The weekly produce of one furnace is about 900 ctrs.

Königshütte has six blast-furnaces, and the foundations of two others are laid. The weekly produce of each furnace is about 1100 ctrs. (in 1861 exactly 1095 ctrs.). The ores are clay ironstones of 30 % produce, and brown iron-ores of 25 % to 28 % (often only 20 %).

For 1 ctr. of pig-iron were required [illegible] ctrs. of iron-producing material, [illegible] ctr. of limestone, and [illegible] ctrs. of coke.

Experiments were made to produce bricks of the powder of poor iron-ores, and to smelt with raw coal. If the Prussian Government enters into competition with private individuals in its works, it always publishes these experiments, etc., for the benefit of the whole country.*

There are, besides these Royal works, [illegible] private works with [illegible] blast-furnaces, [illegible] of which were in blast in [illegible].

The produce of all the coke-furnaces was as follows:—

Name.		In blast. No. of blast-fur.	Produce. Ctrs.
Royal Works	— Königshütte	5	[illegible]
..	— Gleiwitz	1	[illegible]
Private ..	— Laurahütte	4	[illegible]
..	— [illegible] Hütte	4	[illegible]
..	— [illegible] Hütte	3	[illegible]
..	— Vulcanhütte	4	[illegible]
..	— Donnersmarckhütte	4	[illegible]
..	— Hubertushütte	4	[illegible]
..	— Antonienhütte	2	[illegible]
..	— Friedenshütte	1	[illegible]
..	— [illegible]hütte	1	[illegible]
..	— Redenhütte	2	[illegible]
..	— Eintrachthütte	1	[illegible]
..	— Kattowitzer Hütte	1	4,571
		37	[illegible]

Most of the ores are very poor, the brown iron-ore yielding only from 20% to 30% of iron; but the clay ironstone yields 30% to 40%. The brown iron-ore is nearly all earthy and in a dry state, like powder, and contains a considerable amount of lead and zinc, particularly the latter, which accumulates near the top of the furnace, in the form of a solid incrustation (*Gichtschwamm*). The coal is semi-bituminous, often anthracitic, and is frequently impregnated with much sulphur, so that if even it were possible to use it raw, the sulphur would be often an obstacle.

B. *Charcoal-furnaces.*—There are two Royal works—Malapane and Kreuzburger Hütte, each with 1 furnace.

The dimensions of the furnaces are as follow, and they are nearly the same in all others: 30 ft. high and 7 ft. across the boshes; there are 2 twyers from 1½ to 1¾ in. in diameter.

Small quantities of coke are used in most of these furnaces.

Malapane.—Weekly produce 282 to 300 ctrs. The ores used are clay iron-ores, calcined, of from 30% to 40% produce, and earthy-brown iron-ores.

The charcoal is chiefly derived from fir-trees (Kiefer), and only in small proportion from beech and other trees.

1 Klafter wood (=108 cub. ft.) gives 57 to 59 cub. ft. of charcoal.

For 1 ctr. pig-iron, 18·16 (sometimes only 16) cub. ft. of charcoal are required, and 0·61½ ctr. of limestone.

Castings are produced direct from the blast-furnace (there is a

* The Prussian Government is as keenly alive to its own pecuniary interests as private individuals, and has entered into active competition with private firms.—J. P.

Schöpfheerd), and the establishment is celebrated for its chilled castings, such as hard rolls and railway-wheels.

Kreuzburger Hütte.—The furnace charges are nearly the same. The blast-furnace has 3 twyers of 1⅛ in. in diameter. The pressure of the blast is from ½ to ⅝ lb. per square inch, and the temperature from 60° to 90° R. (167° to 234·5° F.).

The produce of all the different charcoal-works which are situated on banks of rivers and rivulets, dispersed in the preceding districts, is as follows:—

	Name.	In blast. No. of blast-fur.	Produce. Ctrs.
Royal Works ...	Malapane	1	14,098 N.[6]
,, ...	Kreuzburger Hütte	1	14,390 N.
Private ,, ...	In the districts (Kreis)[7] of—		
	Rosenberg	5	122,259 N.
,, ...	Lublinitz	8	107,964 N.
,, ...	Gleiwitz	5	99,345 N.
,, ...	Beuthen	5	77,496 N.
,, ...	Gross Strehlitz	6	58,410 N.
,, ...	Rybnik	2	30,006 S.
,, ...	Cosel	1	29,200 S.
,, ...	Pless	2	28,585 S.
,, ...	Oppeln	2	23,700 N.
,, ...	Kreuzburg	1	14,988 N.
,, ...	Falkenberg	1	2,425 N.
		40	622,866

(inclusive of 2875 ctrs. of Pig Steel Iron.)

1861.—Price of charcoal pig .... 1·5 Thaler[8] = 4*s.* 6*d.*
,, coke ,, ... 1·1 to 1·2 Thaler.*

* The price of coke-pig has risen considerably, and at the beginning of 1863 it was 1·5 thaler (=4*s.* 6*d.*) per ctr.

In Upper Silesia are produced:—

Value of 1 Tonne.			
1. 6·94 sgr.[9] ...	577,173 tonnen (1 t. = 7½ cub. ft.),		brown iron-ore (from Muschelkalk).
2. 28·27 ,, ...	47,562 ,,	,,	clay ironstone from the coal-measures.
3. 26·44 ,, ...	95,581 ,,	,,	clay ironstone from the Oölites and Tertiaries.

The pig-iron obtained in the charcoal-furnaces is excellent; it is used partly for castings, and is mostly light grey; but if for chilled castings, mottled pig produced with less fuel is employed (Rohgang). If only the ores No. 3 (clay ironstones) are used, a pig-iron good for steel-making is easily obtained.

Very good ground-plans of the larger works of Upper Silesia are given in the following work: *Studienreise der Studirenden des Berliner Gewerbeinstituts, durch die Provinz Schlesien. Berlin,* 1859-1861.

2. *Lower Silesia and county of Glatz.*—The works are situated partly in the Government district of Breslau, and partly in that of Liegnitz. The ores used at the works in the Lower Silesia district of Breslau belong principally to the crystalline slates and granite; magnetic iron-ore occurs near Schmiedeberg, in gneiss, together with brown iron-ore

[6] N. means the northern, S. the southern charcoal district.

[7] That is, the district round a larger town. A province is divided into government-districts, and a government-district into several Kreise.

[8] 1 Thaler = 3*s.*

[9] 1 Sgr. = $\frac{1}{30}$ Thaler.
1 ,, = $\frac{1}{10}$ shilling.

near Rosengrund, Neudorf and Johannisberg, Lerchenberg and [illegible] in [illegible] state; and red iron-ore in lodes and beds at different places near Kolendorf and Willmannsdorf. In addition, the coal-measures of Lower Silesia yield argillaceous ores.

In 1861 the ores raised were as follows:—

	Tonnen.	At Ctrs. per t.	Value sgr.
1. Brown iron-ores of Neudorf and Johannisberg	[illegible]	7·2	3·[illegible]
2. Clay ironstone [illegible] coal-measures	[illegible]	7·2	[illegible]
3. Blackband do.	[illegible]	6·4	[illegible]
4. Red iron-ore from Kolendorf and Willmannsdorf	[illegible]	[illegible]	5·[illegible]
5. Magnetic ore from Schmiedeberg	[illegible]	[illegible]	5·[illegible]

There are only six blast-furnaces at four works. The largest is Vorwärtshütte, near Waldenburg, which smelts especially the magnetic ore of Schmiedeberg with coke.

In 1861, one furnace only was in blast at Schreckendorf, and made [illegible] ctrs. of pig-iron, charcoal being the fuel.

3. *Prussian Saxony.*—In Prussian Saxony there are several blast-furnaces, in which are smelted brown, red, and magnetic iron-ores from older formations, or crystalline rocks; but, notwithstanding the richness of the ores is great, these furnaces, owing to the want of cheap fuel, are of no great importance.

The fuel is charcoal, sometimes intermixed with a little coke. The principal work is that of Count Stolberg, at Ilsenburg, in the Harz. The ornamental castings here produced are widely known. There are also rolling and wire-mills.

The yield from 2 blast-furnaces was 11,800 ctrs. of pig-iron, and 13,400 ctrs. of castings. Red, brown, and magnetic iron-ores from Elbingerode are principally smelted.

There are also works in the Government district of Merseburg, Josefshütte, near Rottleberode, and Prinz-Carlshütte, near Rothenburg; but in 1861 they were not in operation.

In addition to these works are others in the Thuringian departments of Prussia, districts of Ziegenrück and Schleusingen: the former are widely celebrated for the excellent quality of the iron made from the pig, and used for the small-arm manufactories at Suhl; the latter have beautiful spathic ores near Kamsdorf. The three blast-furnaces (Hoh- and Blauöfen) made 6574 ctrs. of pig-iron.

In the Prussian departments of Prussian Saxony were produced:—

	Tonnen.	At Ctrs. per t.	Value p. ctr. sgr.
Brown iron-ore	4819	7·2	2·86
Clay ironstone	494	6·4	4·69
Spathic iron-ore	2488	8·7	3·47
Red iron-ore	7500	8·8	2·17

4. *The lowland of North Prussia.*—Including, 1. The Government district Liegnitz of Silesia; 2. The province of Saxony, excepting the works under the former divisions (2 and 3); and 3. The provinces of Brandenburg, Pommern, Posen, and Preussen.

In those districts bog iron-ore is the material employed, charcoal being the fuel, sometimes in admixture with coke, and water the usual motive power. The ore is spread about the country in enormous quantities

near the surface, and is, therefore, easily gotten. The presence of phosphorus in it renders it suitable for the production of pig-iron adapted for castings, particularly for pots, domestic stoves, cannon balls, etc. Some of these ores, called "frische Erze," have a black, bright fracture, and they are the richest; but the pig-iron which they yield is said to be the most brittle; others, which are earthy in appearance, are preferred, notwithstanding they are poorer. The produce of iron varies from 20 °/₀ to 29 °/₀. Some of the following works, in addition to bog ores, smelt clay ironstones, etc., from other localities. The furnaces are 25 ft. to 30 ft. high, and 5 ft. to 7 ft. wide at the boshes; 1 to 2, seldom 3, twyers are employed. The weekly produce is from 180 to 300 ctrs.

There is one Royal work at Wondolleck (Government district of *Gumbinnen*, Prussia Proper), where pots are made and enamelled. A gas puddling-furnace is also in operation there.

In the Government district of *Liegnitz* are 15 works, with 20 blast-furnaces, and 18 in blast. In 1861 they yielded 212,785 ctrs. of pig-iron, which was run direct from the furnace into castings.

In the Government district of *Bromberg* are 2 blast-furnaces, 1 in blast, which yielded 6500 ctrs. of castings.

There are several blast-furnaces dispersed through the provinces of *Pommern* and *Brandenburg*, as at Torgelow, Pleiske, Vietz, Peitz, Althammer; but they only continue in blast long enough to supply the need of the inhabitants in the neighbouring country.

In the province of *Saxony*: 1. *Tangerhütte.* In 1861 this work, which has a good foundry and enamelling work, made 12,456 ctrs. of castings and 5592 ctrs. of cast-iron (waste) from the blast-furnace. 2. The iron-work of *Lauchhammer*, widely renowned for its beautiful castings. It is the same work in which have been cast many of the bronze statues for Berlin and other places (*e.g.* Kiss's Amazon, and Rauch's Frederic the Great). At this work were made from the furnace 13,440 ctrs. of pig-iron, and 22,004 ctrs. of castings. Chiefly bog iron-ore is used, but in admixture with brown and magnetic ores from the kingdom of Saxony.

Bog iron-ores were worked in the following districts:—

Province of	Silesia	34,766	tonnen at 5 ctrs. per t.
,,	Prussia Proper	2,156	,,
,,	Posen	668	,,
,,	Saxony and Brandenburg	34,174	,,

II. *The Western Provinces of Prussia.*—A. *The country on the right of the Rhine.*—The iron-works in Westphalia and Rhenish Prussia are to be classified in two groups: one north, in the coal basin of the Ruhr; and one south, in the hilly country, particularly that of Siegen.

1. *The works of the coal basin.*—Until about the middle of this century charcoal was the fuel in nearly all the works; and bog iron-ores of the flat country the sole ores. Subsequently other ores and also coke were introduced; and since 1850 an entire change has taken place. Now charcoal is scarcely used. The blast-furnaces of the districts of Minden and Münster produced 87,205 ctrs. of charcoal pig; bog iron-ores were smelted only at Friedrich Wilhelmshütte, near Gravenhorst, in admixture with $\frac{1}{3}$ brown iron-ore, the fuel now being charcoal and formerly compressed peat; and at Holter Hütte, near Bielefeld.

In 1857 the yearly produce of this country was only little more than [illegible] ctrs.; whilst in 1861 were produced more than 3,000,000 ctrs. of pig-iron.

The iron-ores are in part derived from the coal-measures, and in part from the cretaceous, liassic, magnesian, and carboniferous limestone formations; those from the first consist chiefly of black-band ironstone, though ordinary argillaceous and true spathic ores of importance also occur in these measures, and those from the other formations are red and brown ore.

The produce of black-band and spathic ore from the coal-measures was about 4,550,000 ctrs. But there are now smelted here large quantities of spathic ore from Siegen, and red ores from the river Lahn, and in smaller quantities from the country near Brilon.

At the *Aplerbecker Hütte*, ores from the green sand and red iron-ores from the country near Brilon are employed; at *Hasslinger Hütte* (3) and *Hörde*, black-band; at *Altenbecker Hütte*, and the work *Porta Westphalica*, jurassic ores (oölitic); at *Friedr. W. Hütte* and *Holter Hütte*, bog iron-ore; all the other ores from the coal-measures in admixture with the above-mentioned ores.

The furnaces are mostly built on the Scotch and Belgian plans, and are about 50 ft. high.

Henrichshütte furnaces:—

	No. 1. ft.	No. 1. in.		No. 2. ft.	No. 2. in.
Height	54	0	...	54	0
Top diameter	9	6	...	8	8
Width at the boshes	15	3½	...	15	2
Hearth at the top	2	10	...	4	9
,, at the bottom	3	11½			
There are two twyers, which are above the bottom	2	5	...	2	5

Hasslinger Hütte.—The furnaces are after the Scotch model: height 45 English feet.

	Feet.
Top diameter	9
Width at the boshes	16
Hearth	7
Number of twyers	6

In 1861 the produce of the larger works was as follows:—

Name.	Furnaces. In blast.	Furnaces. Out of blast.	Produce. Ctrs.
1. Henrichshütte, near Hattingen	3	1	452,400
2. Hörder Hütte	4	3	445,803
3. Hasslinghauser Hütte, Neuschottland	2	0	424,300
4. Oberhausen (*Jacobi, Haniel and Huyssen*)	4	0	565,045
5. Phönix III., near Kupferdreh	1	2	266,845
6. Johannishütte, near Duisburg	2	0	253,037
7. Friedrich Wilhelms Hütte, near Mühlheim	2	0	184,056
8. Phönix II., near Ruhrort	1	2	156,814
9. Niederrheinische Hütte, near Duisburg	2	0	144,239
10. Phönix I., near Berge Borbeck	1	3	122,117

There are altogether (including smaller works) 19 works, with 17 furnaces out of, and 33 in, blast; and in 1861 the make was 3,018,272 ctrs. of pig-iron. The price of pig-iron per ctr. was about 1 Thaler 9 sgr. (= less than 4*s.*). It was chiefly forge-pig of good quality.

There are some other works not belonging particularly to this group, which are supplied with coke from this coal basin: for instance,

Dürscheider Hütte and Britannia Hütte, on the right bank of the Rhine, and one work near Neuss on the left bank. The first two were out of blast in 1861; the Neusser Hütte produced from 1 blast-furnace 115,957 ctrs. pig-iron.

2. *Southern country.*—The most important localities in this district are Siegen and the vicinity. Splendid lodes of spathic and brown iron-ores occur there, and also specular red iron-ores. The first two descriptions are rich in manganese, and very pure; whilst south and north of this district, where the younger Devonian crops out, beds of an excellent red iron-ore appear, connected mostly with hyperite (a peculiar granite-like rock) and schalstone (a peculiar hornblendic rock.)

a. Works in the district of Siegen and the vicinity.—The blast-furnaces of this country are very old. It is certain that in the beginning of the 15th century pig-iron was made in "blau" or "hohöfen;" and here it seems the invention of blast-furnaces originated. The pig-iron had always a very high and world-wide reputation; but slow progress in the way of improvement was made, in consequence of the curious old practice that several, and often many, persons were the joint owners of a furnace, and each, during one or two days in succession, smelted his own materials.[1] The opening of two railways last year has had a great influence in rendering it possible to use coke; notwithstanding charcoal always will continue to be employed for the best sorts of spiegeleisen. The first experiment with coke was made at the (then Royal) Loherhütte in 1855. Formerly the furnaces were all either square or octagonal in internal section; and it was only in 1840 that furnaces circular in section were introduced.

The greatest part of the spathic ores is calcined.[2] The newest kilns are 23 ft. in height, and 13 ft. wide; and the fire-place is from 4 ft. to 7 ft. square. They may contain as much as 500 cub. ft.

Dimensions of some blast-furnaces:—

	Total Height.	Hearth, height.	Top, width.	Boshes, width.	Angle of boshes.
	Feet.	Feet.	Feet.	Feet.	Degrees.
1. Burgholdinghausen	34	5	$3\frac{1}{2}$	10	48
2. Müsen	27	$4\frac{2}{3}$	$2\frac{11}{12}$	$8\frac{1}{4}$	50
3. Lohe.............................	40	$3\frac{1}{2}$	$4\frac{11}{12}$	11	65
4. Sieghütte........................	27	5	$2\frac{3}{4}$	$8\frac{1}{2}$	50
5. Gosenbach	32	5	4	11	50

Dimensions of hearth in inches.

	Bottom.			Top.		
	Broad.		Deep.*	Broad.		Deep.
1.	25	×	27	30	×	32
2.	26	×	26	27	×	27
4.	28	×	30	36	×	38
5.	30	×	32	36	×	38
3.	34 diameter.			42 diameter.		

* *i. e.* from front to back. All, except No. 3, are rectangular in horizontal section.

[1] This practice is still continued at some small lead-smelting works in the western provinces of Prussia.

[2] A calcined spathic ironstone from Stahlberg (Müsen) contains, according to Schnabel's analysis:—

Protoxide of iron (?)	84·60
Protoxide of manganese...............	12·47
Lime	0·81
Magnesia	1·96
Silica	0·16
	100·00

The charges usually consist of ⅔ calcined [illegible] spathic ore and ⅓ brown [illegible] with more or less red iron-ore.

It is only exceptionally that spathic ore is smelted raw.

For spiegeleisen [illegible] spathic ore is nearly exclusively used. Limestone and sometimes lime are used as flux and slag-[illegible] for the production of spiegeleisen.

> The [illegible] from [illegible] of charcoal of [illegible]
> The [illegible] from [illegible] and from 15 [illegible] to [illegible]
> [illegible]
> The charge of [illegible] from [illegible]
> .. [illegible] .. [illegible]

The produce of [illegible] cwts. The Harkerhütte [illegible] cwts., and even [illegible] cwts. exceptionally.

The [illegible] charcoal furnace produced on an average

		with only charcoal [illegible] Ctrs.
The [illegible] furnace	..	.. [illegible] ..
..	..	⅓ coke [illegible] ..
The Lohe furnace	..	only charcoal [illegible] Ctrs.
..	..	[illegible] coke [illegible] ..
..	..	⅓ coke [illegible] ..

Commonly the produce decreases as soon as coke is employed, solely because the blowing-engines are not powerful enough: for the Lohe furnace has a powerful engine, and, in consequence, a higher produce with coke is there obtained.

Rarely the period during which a furnace is uninterruptedly in blast (*Campagne*) exceeds a year.

Weight of materials used:

1 scheffel of raw spathic ore*		....	1·95 to 2·50 ctrs.
1	..	calcined ore	1·85 to 2·10 ..
1	..	brown iron-ore	1·50 to 1·8[illegible] ..
1	..	red [illegible] ore	1·[illegible] to 2·[illegible] ..

On an average for 10 ctrs. of pig are required 13 or 14 Scheffel of raw spathic ore.
.. .. spiegel pig are required 11–12 of raw spathic ore of best quality.

* 1 Scheffel = ¼ tonne = $1\frac{1}{2}$ cub. ft.

As above stated, calcined spathic and brown (with some red) ores are used for pig, and of these materials are required

15·2 ctrs. of calcined spathic ore.
7·1 ,, brown and red iron-ore.

22·3 ctrs. ores, *i.e.* ores of about 45 %.

The average amount of limestone is 0·42 to 0·6 ctr. for 1 ctr. pig, smelted with charcoal.
.. .. 1·0 to 2·6 .. 1 .. ⅓ coke.

At works where spiegeleisen is chiefly and purposely made, only from 70 % to 90 % of true spiegeleisen is produced. In that case, for 10 ctrs. of spiegeleisen are required from 10 to 12 tonnen (1 ton. = 7¼ cub.) of charcoal; for common pig, 8 to 9 tonnen; or for spiegeleisen about 102 to 120, and for pig 80 to 90, of charcoal for 100 in weight. Coke is said to be used in the ratio of from 117 to 120 to 100 of pig in weight. All these numbers are averages, but they very often differ in the various works, as might be inferred from the different materials used, etc.

Besides those works, there belong to the same group several iron-

works outside the boundary of the Siegen district, viz. the Royal works and the private works near Sayn and Neuwied, situated on the banks of the Rhine. In some of these furnaces only coke is used, in others charcoal; in some only spathic and brown iron-ores are smelted, in others red and brown iron-ores from the Lahn river are used in addition (Nassau and Prussian Wetzlar). Further; there is the Friedrich Wilhelmshütte, near Siegburg, where the same materials are also smelted, with the addition of sphærosiderites of the tertiary (brown coal) formation, and similar ores as at the works mentioned below under *b*; and lastly, the Eintrachtshütte at Hochdahl, both using only coke in large furnaces.

The names and produces of the most important pig-iron works in the Siegen district in 1861 are as under:—

Name	Produce. Ctrs.	Name.	Produce. Ctrs.
Birlenbacher Hütte	64,600	Bendorfer Hütte	38,484
Hardter ,,	56,000	Eiserner ,,	37,500
Tiefenbacher ,,	55,590	Wissener ,,	35,972
Alte Wisser ,,	52,823	Hainer ,,	35,000
Eiserfelder ,,	47,400	Niederschelder ,,	34,000
Sieghütte ,,	45,900	Marienborner ,,	33,120
Gosenbacher ,,	42,000	Tischbacher ,,	32,400

Several new large works are now built near Siegen.

The Royal works at Sayn produced, in 3 furnaces, which together were only 82 weeks in blast, 156,693 ctrs.; Hermannshütte, near Neuwied, 51,976 ctrs.; Friedrich Wilhelmshütte, near Siegburg, 153,800 ctrs.; Eintrachtshütte, near Hochdahl, 347,602 ctrs.

Royal Iron-works at Sayn.—1. One coke-furnace made weekly 997 ctrs., mostly for foundry purposes. For 100 by weight of pig were used 274 of ore, 108 of limestone, and 132 of coke.

2. Another coke-furnace made weekly 3042 ctrs. of forge pig; and used for 100 by weight of it 227 of ore (spathic and brown ore from the Royal mines, red ore—upper Devonian—from Wetzlar), 86 limestone, and 123 of coke.

3. The charcoal-furnace for gun-foundry iron yielded weekly 453½ ctrs.; and for 100 by weight of pig, 256 of ore, 47 of limestone, and 143 of charcoal were required.

The pig-iron of this establishment is widely celebrated, and the prices paid for it often greatly exceed those for the produce of any other works.

The furnace No. 2 has the following dimensions:—Height, 48½ ft.; height of the hearth, 7 ft.; from the bottom to the boshes, 22 ft.; top diameter, 9 ft.; width at the boshes, 15 ft.; width of the hearth at the upper part, 4 ft.; ditto at the lower part 3½ ft.; height of the twyers above the bottom, 3½ ft.; 3 twyers of 2½ to 2¾ in. in diameter; pressure of the blast, 2¼ to 3 lbs.; temperature of the blast, 100° to 135° Reaum. (= 257° to 336° F.); gases taken off for heating the boilers and air-apparatus.

b. Other works.—There is one group of small works near Ründeroth, where ores, occurring at the surface of the Devonian series, called Lenne-slates, are smelted. The fuel is charcoal, sometimes in admixture with small quantities of coke. They are of no great importance.

Several blast-furnaces which use the brown and red iron-ores of the middle and upper Devonian formation are situated near the northern limit of the mountainous country; but though they may become of considerable importance when connected by railways with the Ruhr coal basin, there is now only one worth mention in which the red iron-ores near Brilon are exclusively used. It is called Bredelar, and is well known for its tough and strong pig. There are also some works in the district of Wetzlar; but in 1861 they were not in operation. Their material is also principally the red iron-ore from the upper Devonian. These red iron-ores contain earthy matters, in such proportions that no flux is necessary.

In the whole of this district—viz. II. A. 2. (*a* and *b*) the southern part of the country right of the Rhine—are 53 iron-works, with 74 blast-furnaces, 57 of which were in blast in 1861, and produced 1,958,474 ctrs. of pig-iron, 35[illegible] ctrs. of which were made with charcoal, and [illegible].044 with a mixture of charcoal and coke.

Private mines produced in this district:—

14[illegible],[illegible]24	tonnen*	of	Brown iron-ore.
3[illegible],[illegible]	..		Spathic ..
4[illegible],155	..		Clay ..
1[illegible]3,183	..		Red ..
6[illegible],[illegible]	tonnen		

The Royal mines produced 38,378 tonnen of spathic and brown iron-ores.

Prince's mines (Standesherrliche) produced:—

13,610	tonnen*	of	Brown iron-ore.
52,965	..		Spathic ..
11,062	..		Clay ..

* 1 tonne = $7\frac{1}{3}$ cub. ft.

B. *The country left of the Rhine.*—Left of the Rhine are four groups of works: those connected with the coal basin of the Inde; those connected with the coal basin of the Saar; those in the mountains of Eifel, *i.e.* north of the river Mosel; and those in the mountains of Soonwald, south of the river Mosel.

1. *Inde basin.*—In 1861 here were two works; only one is of importance, the Concordiahütte. Two of the three furnaces belonging to it were in blast, and produced 270,000 ctrs. of pig-iron. The ores are partly from the neighbourhood, out of the carboniferous limestone and upper Devonian series, partly from Nassau, and other places.[a]

2. *Saar basin.*—The works in or near this coal basin use coke, and chiefly make forge-pig. There are 6 works, with 19 furnaces, of which 13 were in blast in 1861, and produced 770,247 ctrs.

[a] The first ore occurs in small angular compact lumps, generally varying in size from a walnut to a pea, mixed with much ore in a pulverulent state. On this account the ore could not be directly smelted. It is, therefore, subjected to a washing process, and the products are lumps fit for smelting and ore mud or slime, which is left to consolidate in shallow pits. When it has thus acquired the proper degree of consistency, it is fashioned into bricks, which, after the usual processes of drying and burning, are ready for smelting. The bricks are tolerably compact. The process is reported to be economical; but in this respect much must depend on local circumstances.

The most important are :—

Burbacher Hütte (4 furnaces)	3	in blast, produced	349,048 ctrs.
Neunkircher	5	,,	306,511 ,,
Geislauterner (2 furnaces)	1	,,	42,606 ,,
Betlinger	1	,,	34,714 ,,

Only 1 furnace of Neunkircher Hütte used *charcoal* and coke.

The ores are chiefly from the coal-measures of the Saar; but ores are also brought from other localities, particularly Nassau.

3. *Works in the Eifel.*—The Eifel Mountains abound in excellent iron-ores, but as yet this district is not opened by railways; and as wood is scarce, the iron industry cannot flourish; the formerly celebrated and flourishing works of the Schleidener Thal[4] decline more and more every year.

They are mostly small charcoal-furnaces, dispersed in the valleys, 11 of which produced 111,677 ctrs., namely—

In the Government district of Aachen	6 furnaces	produced	42,730 ctrs.
,, ,, Coblenz	1	,,	9,359 ,,
,, ,, Trier	4	,,	59,588 ,,

There were 9 other blast-furnaces not in blast.

Only one coke-work, called Quint, is situated in this district, near Trier. It has 5 furnaces, 4 of which yielded, in 1861, 213,160 ctrs. Occasionally for foundry iron, coke and charcoal are used in admixture.

The charges are—

1.		2.
15%	......	20% red iron-ore.
40%	......	30% ore from Luxemburg.
35%	......	50% clay iron-ore.
10%	......	... cinders.
40%	......	30% limestone.

4. *Works of the Soonwald.*—The ores are clayey (often a little phosphoric) brown iron-ores, occurring for the most part superficially in decomposed Devonian rocks. The fuel is charcoal. They produce a good foundry pig-iron.

The most important works are :—

	In blast.	Produce. Ctrs.
Rheinböller Hütte (3 furn.)	2	46,267
Stromberger ,, (1 ,,)	1	21,585
Gräfenbacher ,, (2 ,,)	2	24,117
Asbacher ,, (1 ,,)	1	6,939

III. *Hohenzollern Counties.*—The ores are pisolitic ores from the Oölite formation (superficial). There are some very good works here.

1. *Laucherthal*, 2 furnaces, 1 in blast, produced 22,014 ctrs.; furnace, $33\frac{1}{8}$ ft. high; width at the boshes, $7\frac{3}{8}$ ft.; top diameter, 3 ft.; width at the upper part of the hearth, 29 in., and at the bottom, 19 in.; 2 twyers.

2. *Thiergarten.*—1 furnace produced 21,724 ctrs.; furnace, 31 ft. high; width at the boshes, $7\frac{1}{12}$ ft.; top diameter, 3 ft.; width of the hearth at the bottom, 17 in.; 3 twyers. Daily produce, 60 ctrs.

Both are charcoal-furnace works.

[4] Here the well-known "Distillation process," a refining in the blast-furnace itself, has been carried on for centuries. Before tapping the twyers are inclined and the blast directed upon the molten pig-iron in the hearth.

RETURNS.—Iron-Ores Produced, 1861.

District.		Bog ore.	Brown iron-ore.	Clay iron-ore.	Blackband.	Red iron ore.	Magnetic ore.	Spathic ore.	Plastic ore	Total
		Ctrs.	Ctrs.	Ctrs.	Ctrs.	Ctrs.	Ctrs.	Ctrs.	Ctrs.	Ctrs.
Mining district,	Breslau	* 187,990	3,487,218	917,122	10,412	48,781	1830			4,658,101
..	Halle...........	170,870	34,608	2,102	...	60,000	-	91,010		960,071
..	Dortmund......	226,640	910,422	37,512	3,428,568	6,082		1,222,109	10,055	5,881,010
..	Bonn	101,700	3,033,122	741,910	...	1,880,070	.	3,900,044	108,851	9,130,130
									Total	19,000,010

Pig-Iron Produced.

Province.	No. of blast-furnaces. In blast.	No. of blast-furnaces. Out of blast.	Total Produce.	Produce with Coke	Produce with Charcoal	Produce with Charcoal and Coke
			Ctrs.	Ctrs.	Ctrs.	Ctrs.
Silesia	96	42	2,168,536	1,281,205	805,807	81,504
Posen	1	1	6,500	-	6,500	
Prussia Proper......................	1		301		301	
Pommern	-	1	—	.	--	.
Brandenburg	1	3	8,010	..	8,010	.
Saxony	6	6	85,200	–	83,200	2,000
Westphalia[1]	44	10	2,077,430	1,200,827	370,181	506,101
Rhenish Prussia	83	34	4,601,147	3,884,815	142,180	573,813
Hohenzollern	2	1	43,798	—	43,798	–
Total..................	234	104	8,986,777[2]	6,372,037	1,400,272	1,167,508
	338			70·9%	16·2%	12·9%
					100%	

The statistics for 1862 are not yet completed, but the produce is a great deal higher.

* The weights are all in ctrs.

[1] It must be remembered that the Siegen country belongs to the province of Westphalia, whilst the part of the coal-basin near the Rhine belongs to Rhenish Prussia.

[2] From the 8,986,777 pig were 152,523 ctrs. spiegeleisen.

N.B. These tables have been corrected in type by Dr. Wedding.

These notes are from the year 1860 (*November*).

To 100 parts by weight of Pig-Iron.

Name of the Work.	Kind of pig-iron.	Ores. Sphæro-siderites.	Ores. Brown hæmatites.	Ores. Balling furnace cinders (silicate of protoxide).	Ores. Total of ores.	Percentage of pig-iron.	Flux. Limestone (not calcined).	Flux. Blast-furnace cinders.	Total of charges.	Fuel. Coke. Quantity of raw coal used for the coke (w).	Fuel. Coke. Charge.	Weekly make, English Tons. (z).
1. Königshütte..........	Grey	24·20	266·23	48·48	338·84	29·51	121·00	24·20	484·00	409·10	** 206·21	61·10
2. Id., another furnace	Grey											
3. Hubertushütte	Grey	79·48	251·66	13·24	344·32	29·04	119·20	26·49	490·01	402·00	225·17	37·89
4. Friedenshütte	Light grey	7·80	304·10	38·10	350·00	28·57	120·00	..	470·00	392·28	241·50	55·54
5. Redenhütte...........	Light grey	0·00	333·34	17·54	350·88	28·50	122·81	..	473·69	360·90	254·63	49·09
6. Average f. 1–5	Grey	27·87	288 83	29·32	345·27	28·91	120·75	12·67	479·44	391·07	231·32	50·92

Blast.

Name of the Work.	Kind of pig-iron.	Prussian measures. Twyers. No. of.	Twyers. Diameter.	Twyers. No.	Twyers. Diameter.	Pressure of blast.	Heated to degrees Celsius.	$\frac{p^1}{p}$ *	Velocity of blast.	Area of all the twyers.	Coefficient for the loss in conical pipes.	English measures. Blast in 1st section.	English measures. Blast per ton of coal (vide col. w).	Ratio of Oxygen in the blast to 1 part of carbon.
			in.		in.	lb.			ft.	sq. in.		cub. ft.	Cub. feet.	
1. Königshütte	Grey	2	3	1	2¾	2¾	100	1·15	470	20·08	0·85	52·01	115,260	1·19
2. Id., another furnace	Grey	5												
3. Hubertushütte	Grey	3	2¾	..	..	3	0	1·20	537	17·32	0·85	61·65	224,370	2·32
4. Friedenshütte	Light grey	5	2½	..	..	2¼	0	1·15	470	24·54	0·85	37·26	94,801	1·01
5. Redenhütte	Light grey	3	2½	..	..	1¾	0	1·12	424	14 73	0·85	40·15	125,640	1·35

* p^1. = Pressure of blast. p. = Pressure of the atmosphere.

** The usual consumption of coke is much greater. These results must be quite exceptional. Generally 2¼ parts by weight of coke are required to produce 1 part by weight of pig-iron.—J. P.

Dimensions of Blast Furnaces. English Measures.

Name of the Work.	Kind of pig-iron.	With (+) or without (−) taking off the gases.	Top. Diameter.	Top. Area (A).	Boshes. Diameter.	Boshes. Area (B).	Hearth between the tuyeres. Diameter.	Hearth between the tuyeres. Area (C).	Hearth. Upper part. Diameter.	Hearth. Lower part. Diameter.	Height of. Total.	Height of. h	Height of. s	Height of. [illegible]
			ft.	sq. ft.	ft.	sq. ft.	ft.	sq. ft.	ft.	ft.	ft.	ft.	ft.	ft.
1. Königshütte	Grey	−	9·00	63·90	15·45	181·95	3·00	9·03	4·03	3·00	51·10	[illegible]	[illegible]	[illegible]
2. Id., another furnace	Grey	−	8·95	61·00	14·12	155·18	3·33	8·70	4·00	3·00	51·10	[illegible]	[illegible]	[illegible]
3. Hubertushütte	Grey	−	8·44	56·20	14·12	155·18	2·57	5·09	4·03	2·92	51·10	[illegible]	[illegible]	[illegible]
4. Friedenshütte	Light grey	−	9·27	67·40	16·47	213·80	3·10	7·81	4·03	2·57	[illegible]	[illegible]	[illegible]	[illegible]
5. Redenhütte	Light grey	+	7·21	40·83	13·80	140·57	2·57	5·03	4·19	2·92	51·10	[illegible]	[illegible]	[illegible]

Name of the Work.	Kind of pig-iron.	Proportions. A/C	Proportions. B/C	Proportions. w/B	Proportions. s/C	Ores.	Flux.	Fuel.	Labour and Sundries.	Total.
						Thl. sgr. pf.	Thl. sgr. pf.	Thl. sgr. pf.	Thl. sgr. pf.	Thl. sgr. pf.
1. Königshütte	Grey	8·00	19·18	2·22	6·85 }	0 10 4·88	0 1 4·07	0 15 10 82	0 8 4·24	1 0 0·31
2. Id., another furnace	Grey	7·01	18·50	2·51	6·06 }					
3. Hubertushütte	Grey	9·40	28·98	2·10	6·73	0 11 7·85	0 0 11·81	0 14 8 02	0 5 10 09	1 2 10·00
4. Friedenshütte	Light grey	8·00	27·27	1·83	7·08	0 11 2·00	0 2 0 10	0 12 1·70	0 8 5·70	1 8 10 00
5. Redenhütte	Light grey	7·25	26·58	2·41	8·72	0 10 11·00	0 1 9·00	0 14 11 40	0 8 1·10	1 0 8 00

Note. h = Height from the bottom of the boshes to the hearth-bottom. s = Height of the boshes.

ON THE PRODUCTION OF MALLEABLE IRON FROM CAST-IRON.

THE process which is now most extensively practised for the conversion of cast-iron into malleable or wrought iron, is that of puddling. But, before the introduction of that process, the conversion was always effected in a finery or hearth, in which the metal was melted in contact with the solid fuel, and so exposed to the highly oxidizing action of a blast of atmospheric air; and this ancient method is still in operation both in this country and abroad, though at no distant time it will probably be entirely superseded. Charcoal is the only fuel that can be used with advantage, on account of its freedom from sulphide of iron, which exists in all coal or coke in such a degree as injuriously to affect the quality of the iron with which it may come in contact. In the process of puddling, on the contrary, mineral fuel may be employed, because the conversion takes place on the bed of a reverberatory furnace, and there is no contact between the solid fuel and the metal operated upon; and without such contact the sulphur of the sulphide of iron does not pass to any sensible extent into the iron.

Unfortunately we have no simple English verb for the operation conducted in the charcoal finery or hearth, equivalent to the German "Frischen." The word refining might be adopted, if it had not been previously applied to the process of partially decarburizing pig-iron by melting it under coke, and so subjecting it to the influence of a blast of air. The apparatus in this country is designated a charcoal hearth, or charcoal finery; and I shall hereafter employ both indiscriminately, though perhaps it might be more correct to restrict the term hearth to the particular part of the finery in which the metal is treated. Still the hearth is essentially the finery. The word fining may, for want of a better, be and occasionally is adopted to indicate the process; notwithstanding it seems somewhat absurd to designate the process of incomplete decarburization as *refining*, and that of practically complete decarburization as only *fining*; and difficult, moreover, to avoid confusion in the use of these two very similar terms. However, I fear that, for the present at least, there is no alternative; and I shall therefore apply the word fining to the operation of converting cast into malleable iron by the specific process, or series of processes, now to be considered, *i. e.* in a hearth or open fire, urged by a blast of air with charcoal as the fuel.

The modifications which the fining process has undergone in different localities are numerous, but they are substantially the same in principle. The problem is the removal of the carbon from pig-iron, and this is effected partly through the direct action, at a high temperature, of the oxygen of atmospheric air, and partly through the action of the oxygen contained in the oxide of iron generated in the process, or in a compound of oxide of iron expressly added. The reader is recommended very carefully to study the reactions which have been fully described, especially those concerning the reduction of the silicates

of protoxide of iron by carbon, &c. The word cinder is commonly used in our iron-works instead of slag, and I shall accordingly employ the two as synonymous. The cinders which are produced in fining are silicates of protoxide of iron—never more highly basic than tribasic—in association with compounds or mixtures of protoxide of iron and variable proportions of sesquioxide of iron, but chiefly of the former. The cast-iron to be treated is introduced into the hearth in different ways and in the different states of white, mottled and grey; and the manipulations vary somewhat in consequence. But in every case the same object is to be attained, and the same agents are resorted to for the purpose.

Some metallurgical writers have described the modifications of the fining process with a degree of minuteness positively bewildering, and have presented elaborate classifications resting, in many instances, on a remarkably slender foundation; so much so, indeed, that it is impossible to detect any *practically* essential distinction between them. The manipulations, also, have been recorded with wearying precision and monotony, and with an amount of petty details which I venture to think are worse than superfluous. In operations like that of fining, these details must be acquired by experience, and can never be otherwise mastered, so as to be capable of direct application. It is so indeed in every art, properly so called. While I would be the last man to disparage book knowledge, yet I must confess that what I may term descriptive over-refinement may excite repulsion in the mind of the reader, and be therefore mischievous.

The most complete and comprehensive modern treatise on the subject is unquestionably that of Professor Tunner, Director of the Mining School at Leoben in Styria; and I shall freely avail myself of it.[1] The treatise of Wigand on the same subject, previously published, is useful and compendious,[2] and may be consulted with advantage.

Professor Tunner's classification is as follows:—

Once-melting down process.
Einmalschmelzerei.

- I. Austrian slag process.
  Österreichische Schwallarbeit.
- II. Styrian charcoal process.
  Steirische Löscharbeit.
- III. Carinthian charcoal process, with discs of pig-iron.
  Kärntn. Löscharbeit mit gebrat. Blatteln oder mit Kortitsch.
- IV. Siegen once-melting down process.
  Siegen'sche Einmalschmelzerei.
- V. Tyrol process.
  Tyrole Schmiede.
- VI. Lombardy Mügla- and Salzburg sinter-process.
  Lombardische Mügla- und der Salzburger Sinterarbeit.

[1] Die Stabeisen- und Stahlbereitung in Frischherden. 2 vols. 8vo. Freiberg, 1858. Together they contain 609 pages, and there are numerous excellent lithographic and woodcut illustrations.

[2] Frischhüttenbetrieb, oder: Fabrication des Stab- oder Schmiedeeisens. August Wigand. Berlin, 1837. 8vo. pp. 144.

- Walloon process. (*Wallonschmiede.*)
  - VII. Eifel Walloon process. (*Eifler Wallonschmiede.*)
  - VIII. Swedish Walloon process. (*Schwedische Wallonschmiede.*)
  - IX. English Walloon process (*Englische Wallonschmiede.*)
    - 1. Lancashire process. (*Lancashire Schmiede.*)
    - 2. South Wales process. (*Südwales'er Schmiede.*)
  - X. Styrian Walloon process. (*Steirische Wallonschmiede.*)
- German or breaking-up process. (*Deutsche oder Aufbrechschmiede.*)
  - XI. Bohemian running together process. (*Böhmische Anlaufschmiede.*)
  - XII. Swabian process. (*Schwäbische Schmiede.*)
  - XIII. French process. (*Französische Schmiede.*)
  - XIV. Rohnitz process. (*Rohnitzer Arbeit.*)

I propose to select, for particular description, Nos. VIII., IX., X., the only ones which, in the opinion of my experienced friend Mr. Grill of Sweden, are worth describing, and to treat in a cursory manner of the others. Only Nos. VIII., IX., and X. are now in use in Sweden, the old German process being nearly extinct there.

The South Welsh Process.

I am greatly indebted to Mr. Williams, manager of the Morfa Tinplate Works, at Llanelly, Glamorganshire, for the elaborate and accurate drawings made by himself, from which the accompanying large woodcut has been executed.

The apparatus consists of a "melting finery," commonly termed refinery, or running-out fire, to be more particularly described hereafter, and two charcoal fineries or hearths. The pig-iron is melted under coke by means of a blast in the melting finery, and the molten metal is allowed to flow into the two charcoal fineries, supposed to be ready to receive it.

Letters.	Nos.	*Description of the Woodcut, p. 584, 585.*
—	—	
	1	Horizontal plan of melting finery or fire.
	2	Horizontal plan of one of charcoal fineries.
	3	Elevation of melting fire, shown partly in section.
	4	Elevation of charcoal finery.
	5	Front elevation of melting fire.
	6, 7	Front elevation of charcoal fineries.
		N.B. The corresponding parts of the different views are marked with similar letters.
a a	1, 3	Blast-pipes leading from main-pipe.
b b	,,	Water twyers.
		N.B. The angle or dip of water twyer is changed as the bottom of brickwork wears down. In the drawing the bottom is supposed to be newly laid.
c	,,	Water-block, forming the back of fireplace.
d	,,	Cistern for holding workmen's tools.
e	1, 3, 5	Cast-iron plates forming sides of fireplace.
f	,,	Front or cinder-plate.

Letters.	Nos.	
g	1, 4, 5	Cistern from which water twyers are supplied.
h	1, 7	Cistern for cooling finerman's tools, one of these to each finery.
i	6	Recess in masonry for the cistern (*h*) of left-hand finery.
k	4, 6, 7	Small reservoir of water for preventing injury to twyers in case the supply of water should be temporarily stopped.
l	1, 4, 6	Merrit plate in two halves, with frame, in which twyer pipes are adjusted and fixed.
m	,,	Cast-iron plate forming bottom of finery, kept in position by a wrought-iron wedge-bar shown in section in No. 6.
n n	,,	Back and side plates of cast-iron.
o	2, 4, 7	Cinder-plate with holes for the flowing out of molten cinder.
p	,,	Fore-plate or table.
q	4, 6	Apertures in sides of finery, loosely filled with bricks when fires are at work.
r	6, 7	Similar openings in front and back.
s	6	Water twyers.
t	2, 6, 7	Blast-pipe furnished with a moveable nozzle.
u	4, 6	Air-way underneath hearth, into which water is occasionally thrown to cool bottom plate.
x	4, 7	Supports for finermen's bars whilst working the iron. These serve as fulcra.

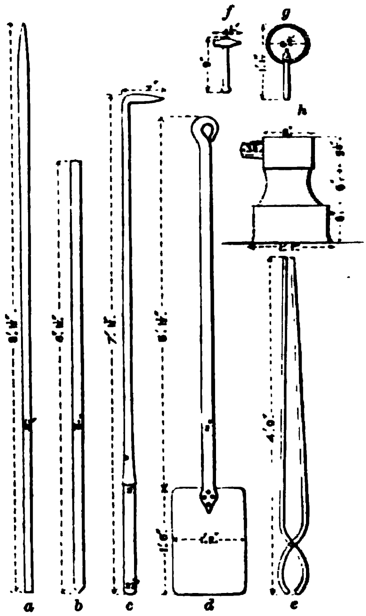


Fig. 106. Tools used in charcoal finery. *a*, pointed bar. *b*, bar with chisel-edge. *c*, hooked bar. *d*, shovel. *e*, tongs. *f*, small hammer for hammering points of bars. *g*, shallow scoop for throwing on water. *h*, anvil.

Description of the process as I saw it conducted at the Morfa Tin-plate Works, Sept. 9th, 1859.—Pembrokeshire pig-iron made at Saundersfoot Furnaces and Cumberland hæmatite pig-iron were employed in admixture, and melted together in the melting finery in quantity sufficient to fill the two charcoal fineries. The melting finery is tapped at the bottom, so that metal alone flows at first, and as soon as the slag formed during the process appears, it is diverted and, as far as practicable, kept apart from the metal; but, nevertheless, some will find its way into the charcoal fineries.

2^h. 10^m. The charcoal fineries having been heated from the last operation, and duly prepared, were filled in succession with molten metal from the melting finery. Some slag escaped along with the metal into the charcoal fineries, where it speedily solidified and was afterwards removed as a crust. This done, a basket of charcoal was thrown in, and the blast, which was cold, let full on. The metal having more or less completely solidified, yet being very friable, was broken up by an iron bar, mixed with the charcoal in the hearth, and heaped up towards the twyer side. Water was thrown at intervals

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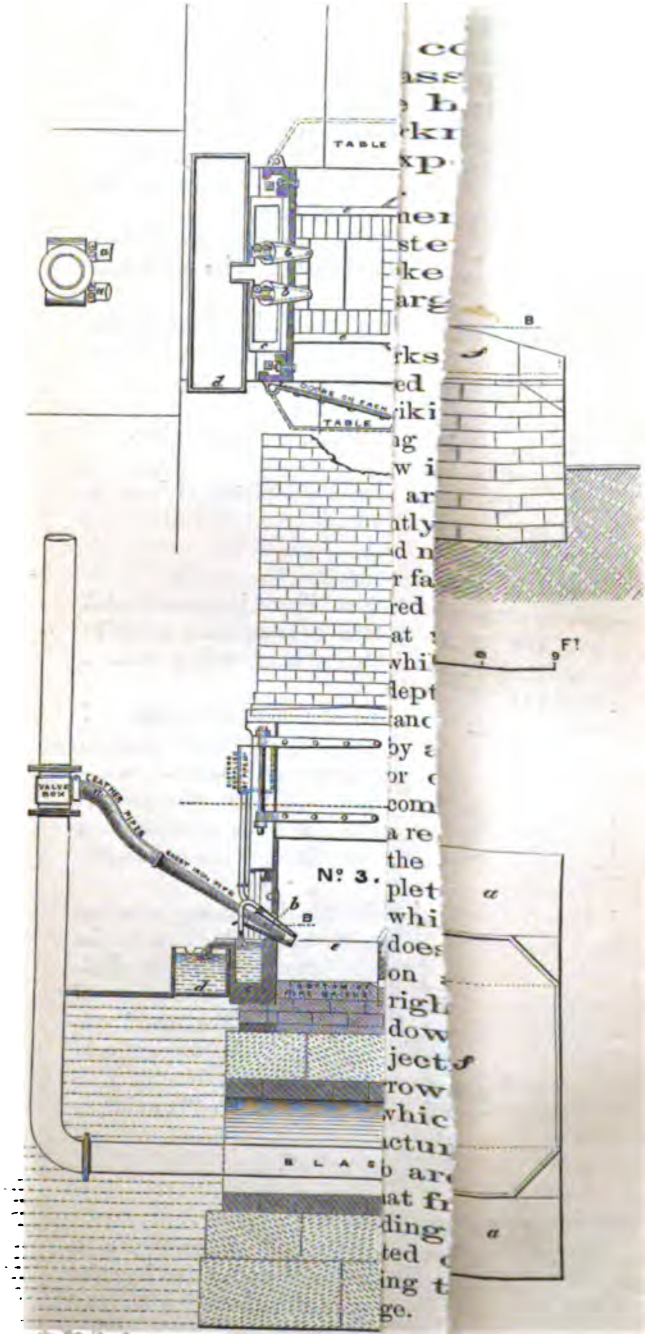

DRAWN BY OCTAVIUS WILLIAMS.

Fig. 107.

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Letters.	Nos.	
—	—	
g	1, 4, 5	Cr̃ngeals around its (comparatively cold) point. , through the hole when the bar is withdrawn,
h	1, 7	C!earth after the "*lump*" is taken out. nen started at their fineries at the same time;
i	6	Rert, brought out an excellent ball some minutes The manipulation may appear rude, but it is
k	4, 6, 7	Sr̃ differ greatly in skill. r Works from 5 to 6 cwts. of pig-iron were melting finery to supply two charcoal fineries. ;e was from 200 to 250 lbs. for each charcoal
l	1, 4, 6	M there were two hammers driven by straps. three times during one revolution by three
m	,,	C̃ng the tail end. From the lower face of the piece with a narrow, flat, rectangular surface, s a similar and corresponding piece projecting Be not used, as it is maintained that the iron
n n	,,	sound without hammering. In first hammer-
o	2, 4, 7	Ciot under, but on the inside of the pieces pro- ce and the anvil respectively.
p	,,	Fout into a narrow rectangular slab 108 (*a*), more
q	4, 6	A;he ends, and about 1¾ in. to 2¼ in. thick, and, ;e still hot, it is nicked across to a considerable h in seven or eight places at about equal dis-
r	6, 7	S!es apart (*d*). This is done under the hammer
s	6	wpplying a bar of iron having a wedge-shaped
t	2, 6, 7	B;hisel-like end (*b*). Occasionally the slab is
u	4, 6	Apletely cut through. The nicked slab, still in
x	4, 7	Sd-hot state, is plunged into cold water, whereby superficial coat of oxide is more or less com-

,ely detached; much hydrogen gas is evolved,
Description of t!ch burns with a yellow flame. This flame
Sept. 9th, 1859.—, not always appear. The slab is next placed
and Cumberland a sort of long anvil with several narrow up-
melted together ,t projecting ribs, so that the nicks may be
two charcoal fin(nwards and about midway between these pro-
that metal alone ing pieces respectively (*c*). Then by striking
the process appe-ended sledge (*e*) over the nicks, it is readily
from the metal ;h are termed "stamps." A stamp weighs about
charcoal fineries-ed edges are bright and crystalline. The end
2^h. 10^m. The ; worked apart, as the iron made from them is
operation, and c·om the other portions, which are duly examined,
metal from the to their degree of soundness or freedom from
metal into the c,r crude metal. Any portions of metal which
afterwards remche hammering are put into the charcoal finery
thrown in, and
having more or.
broken up by an

THE HOLLOW FIRE.

heaped up towamanipulation of the stamps, the hollow fire is
is represented in the accompanying woodcuts,

Fig. 109. Hollow Fire. Front elevation.

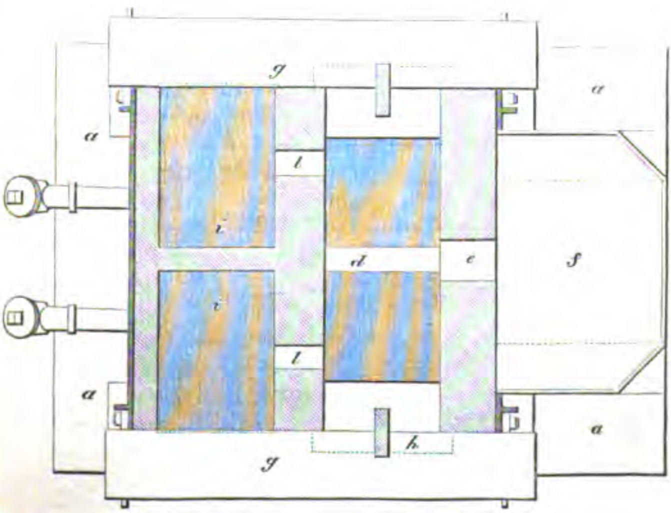

Fig. 110. Hollow Fire. Horizontal section on the line A B, fig. 109.

which have been executed from drawings by Mr. Williams, of the Morfa Tin-plate Works.

Fig. 109. Front elevation.

Fig. 110. Horizontal section on the line A B, figs. 109, 111.

Fig. 111. End elevation, half sectional.

The corresponding parts in the different views are indicated by the same letters.

109, 110, 111, *a*. Platform of stone or brickwork.

109, 111, *b*. Two cast-iron plates covered with 3 in. brickwork, forming the bottom of the fire-place, and which are kept cool by an air-way underneath.

109, 111, *c*. Opening through which the coke and "morsel" are withdrawn when the fire is cleaned. When the fire is in use, this opening is stopped loosely with half bricks and ashes.

109, 110, 111, *d*. Partition between the two fires of 4½ in. brickwork. This partition is now omitted, without any disadvantage to the working of the fire.

109, 110, 111, *e*. Hole through which the fire is supplied with coke, dotted in fig. 109.

109, 110, *f*. Table of cast-iron for holding coke.

109, 110, 111, *g*. "Fore-plates" or rests for "staffs," supported by brackets attached to the cast-iron framework of the fires.

109, 110, 111, *h*. Doors, dotted in fig. 110.

109, 110, *i*. Stoves for heating the iron.

109, 111, *k*. Blast holes.

110, 111, *l*. Holes inside of fire-place communicating with stoves.

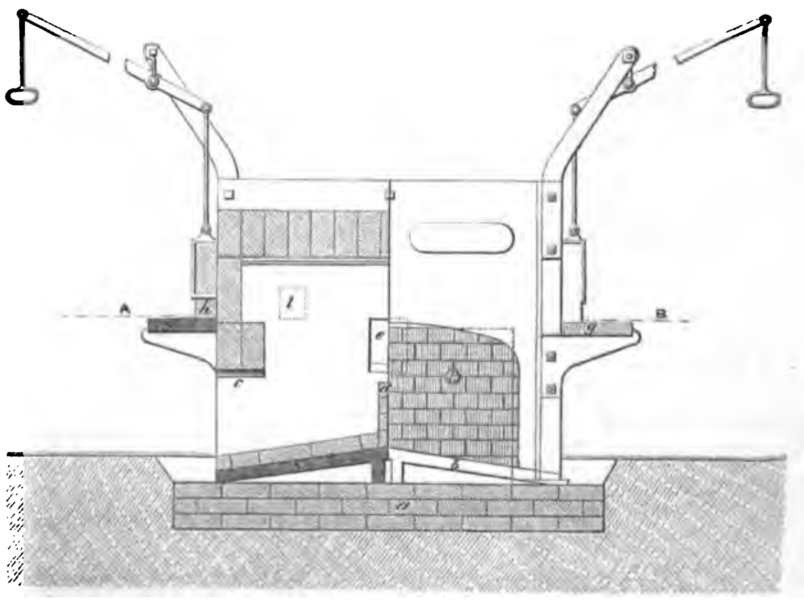

Fig. 111. Hollow Fire. End elevation, half sectional.

The stoves when in use are closed by thin wrought-iron plates, recessed for the handles or staffs. The position of these plates is shown by dotted lines in fig. 110. There is no chimney.

The furnace above described is termed a double hollow fire. It is urged by cold-blast, and consists essentially of two similar reheating or welding chambers, separated from each other by the vertical wall *d*, figs. 109, 110, 111. Each of these chambers is supplied with one twyer, directed downwards at a slight angle. Coke is the fuel employed, and the iron to be welded is heated in the flame from the coke, and never comes in contact with the coke itself. The waste flame passes chiefly backwards through the opening *l*, figs. 110, 111, into what are termed the stoves, where the iron is subjected to a preliminary reheating before its introduction into the welding flame; but flame is always escaping in a greater or less degree at the doors *h*. A very high and equable temperature is attained in the hollow fire; and as the iron is heated entirely by flame, it is not liable to the injury it would receive by contact with mineral fuel, containing sulphide of iron.

The stamps are heated on what is termed the "staff," which is a bar of iron about 4 ft. long, welded at one end to a flat piece or blade of iron, of the same quality as the stamps; it resembles in shape a baker's peel: see fig. 112. They are piled upon the blade of this staff to the extent of about 80 lbs., raised to a welding heat, and hammered out into flat slabs about 6 in. broad and about 2¾ or 3 in. thick. The end of the staff is lengthened from time to time from the pile, with which, after hammering, it forms one mass. The slab is then nicked across the middle of its upper surface, and one half is doubled upon, and welded to, the other in the same manner as in the first instance. By this means the two surfaces of the finished plate are found to be uniform in quality, each, in fact, being derived from that of the underside of the blade of the staff; whereas, before the doubling was resorted to, it is stated that the finished plate had a smooth side, which corresponded to the flat part or blade of the staff. This improvement was introduced in 1820, and is ascribed to Mr. William Daniell. It is known as the invention of "tops and bottoms," and is reported to have been a source of much gain.[3]

The staff, after the slab is separated by the shears for the purpose of being rolled into a bar, consists of little besides the handle or narrow portion, and is represented fig. 112.

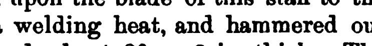

Fig. 112. Part removed to form a bar.

Fig. 113. Part removed to form a bar. Side view.

It requires "mending," and this is effected in the following manner: Two "stumps" are placed on the larger extremity, heated and hammered into a slab of convenient dimensions; the stumps required to complete the bar are then placed on the *same side* of the staff, and

[3] Mr. Ebenezer Rogers on the Manufacture of Tin Plates, p. 16. Proceedings of the South Wales Institute of Engineers, Jan. 1857.

the entire mass is drawn out or hammered into a slab 3 in. thick and 6 in. wide; the "nick" or cleft is made on the staff side, as shown in fig. 114.

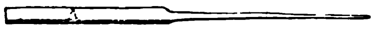

Fig. 114. Part remaining of original staff.

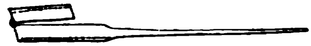

Fig. 115. Staff doubled.

To complete the process the end portion is bent backwards, as shown in fig. 115, and the whole is reheated, welded, and hammered into a slab about 3 in. thick and 6 in. wide; after which the hammered-out piece is reheated, cut off, and rolled.

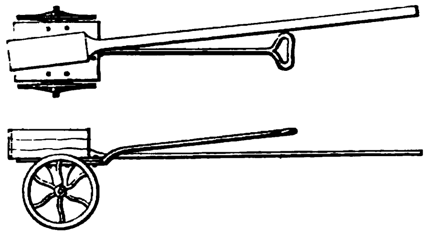

Fig. 116. Carriage for carrying staff to the hollow fire. Plan and side elevation.

According to the late Mr. E. Rogers, the system of manufacturing iron for charcoal plates, as above described, dates from 1807, and was first carried out by Mr. Watkin George, at the Pontypool Iron-works, which have so long enjoyed a high reputation in the tin-plate trade. It was also stated by Mr. Rogers that the process of preparing the best or charcoal iron seemed to have undergone but little change from 1720 to 1807. Before the last date, about 1¼ cwt. of pig-iron was worked at a time into malleable iron in a charcoal finery. The ball was hammered into a bloom under a heavy forge hammer, and then drawn out into bars under the lighter and more quickly moving tilt hammer. Reheating was effected in what was termed the chafery, a sort of blacksmith's forge. The word is clearly of French origin, and derived from "chaufferie."

The following account, published in 1676, of the old process of converting pig-iron into malleable iron, is sufficiently interesting to deserve insertion here[4]:—

"From these furnaces [high blast-furnaces] they bring their sows and pigs of iron to their forges. These are of two sorts, though standing together under the same roof: one they call their Finery, the other the Chafery. Both of them are open hearths, on which they place great heaps of sea-coal, and behind them bellows, like to those of the furnaces, but nothing near so large. Into the Finery they first put their pigs of iron, placing three or four of them together behind the fire, with a little of one end thrust into it. Where softening, by degrees they stir and work them with long bars of iron, till the metal runs together into a round mass or lump, which they call a half-bloom. This they

[4] An Account of the Iron-Works in the Forest of Dean, communicated by Henry Powle, Esq. Philosophical Transactions, 11. p. 931, 1676.

take out, and giving it a few strokes with their sledges, they carry it to a great weighty hammer, raised likewise by the motion of a water-wheel, where applying it dexterously to the blows, they presently beat it out into a thick short square. This they put into the Finery again, and heating it red hot, they work it out under the same hammer, till it comes into the shape of a bar in the middle with two square knobs in the ends. Last of all, they give it other heatings in the Chafery, and more workings under the hammer, till they have brought their iron into bars of several shapes and sizes, in which fashion they expose them to sale."

In the charcoal finery in South Wales the cost of the charcoal consumed per ton of iron made amounts to about 12*s*.

Charcoal Finery used in Sweden under the Name of Lancashire Hearth.

For the drawings from which the accompanying woodcuts (figs. 117, 118, 119, 120) have been executed, and for the description of the process, I am indebted to Mr. Andreas Grill.

The furnace consists essentially of a shallow quadrangular hearth, formed of cast-iron plates *a*, *b*, *c*, *d*, *e*. The hearth-bottom *a* is horizontal; the twyer side *b* is slightly inclined inwards; the opposite side *d*, and the back *c*, are inclined outwards; the front *e* is vertical, and in it there are three round holes for tapping off the cinder. Under the hearth-bottom is a shallow open cast-iron box having a gutter on one side *f'*, and a round hole in the centre of the bottom, *f*, surrounded with a border not quite so high as the box is deep: the box and gutter are cast in one piece. During the working of the furnace, cold water is continually flowing through *f'* and running out at *f*. By this arrangement the hearth-bottom is kept cool. The side-walls above the hearth are protected within by cast-iron plates: see figs. 119 and 120. Hot-blast is used, and there is one twyer *i*, which passes through a thick cast-iron plate set in one of these side plates *g*; it is an iron water-twyer, which is nearly semicircular in section. The narrow end projects over the side of the hearth ¾ in., and the axis is inclined at an angle of about 10° with the horizon. As the charcoal is piled round and above the twyer, the plate *g* is exposed to great heat and consequent destruction; it is made very thick, and may be readily replaced when required. In front of the hearth is a table or platform of cast-iron, *h*, resting at the ends on cast-iron standards. This table is essential for the necessary manipulations. The arrangement for heating and conveying the blast to the twyer is represented by *k*, *k'*, *k''*. The heating apparatus consists merely of a syphon-pipe of cast-iron, set horizontally and exposed to the waste gases of the furnace. There is a throttle valve at *k* for stopping and regulating the blast. The nozzle end of the blast-pipe may be raised or lowered at will by a telescope sliding piece, and may be turned in any direction by means of the union-joint below *k*, fig. 117. The waste gases escape partially through the square opening *l*. At *m* is a cast-iron plate on which pigs

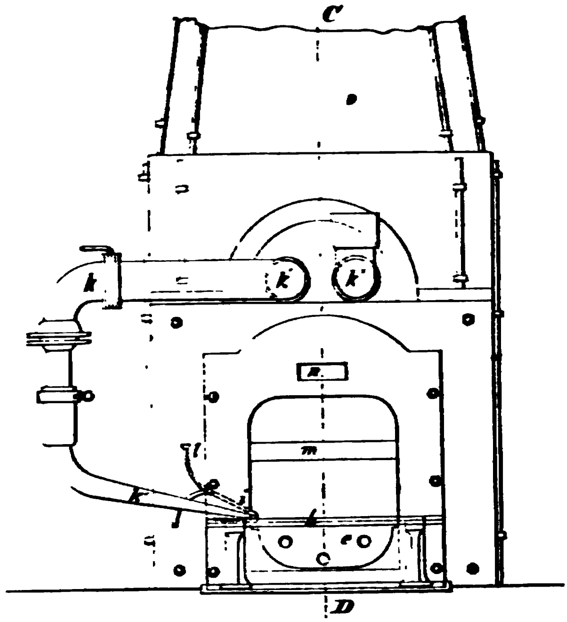

Fig. 117. Swedish Lancashire Hearth. Front elevation.

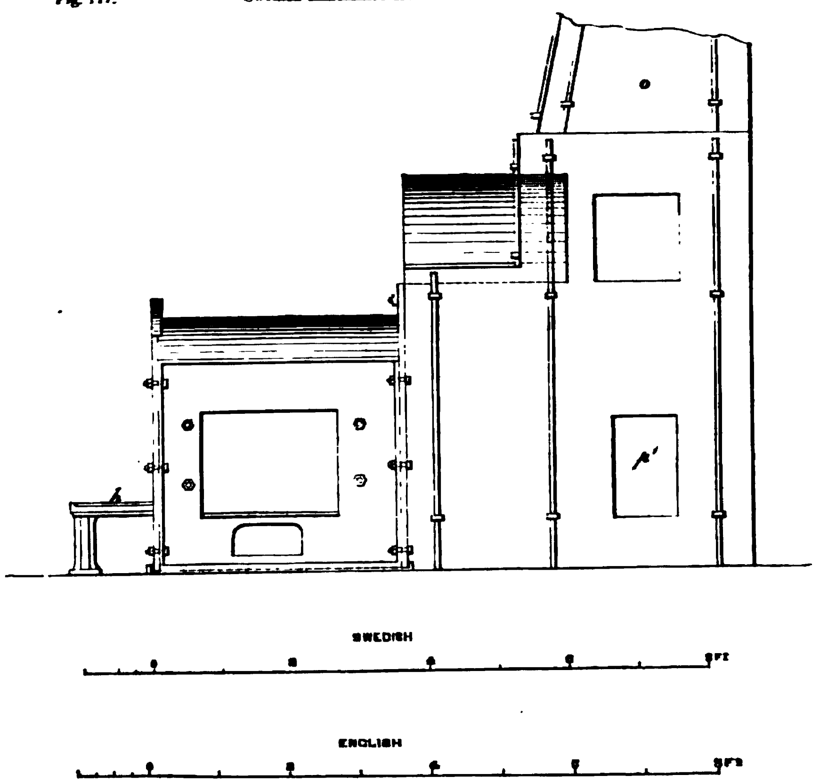

Fig. 118. Swedish Lancashire Hearth. Side elevation.

or blooms may be laid so as to become heated. At *n* is an opening through which an iron bar may be introduced to move the objects on the plate *m*, or clean the arched passage leading from this part to the stack *o*, to which at the bottom is often attached a large chamber

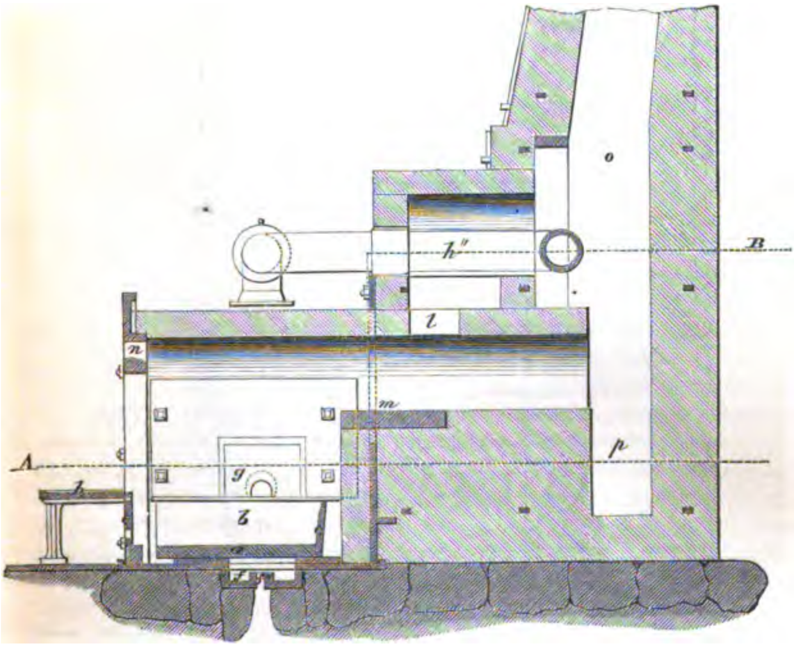

Fig. 119. Swedish Lancashire hearth. Longitudinal section on the lines C D, fig. 117, and E F, fig. 120

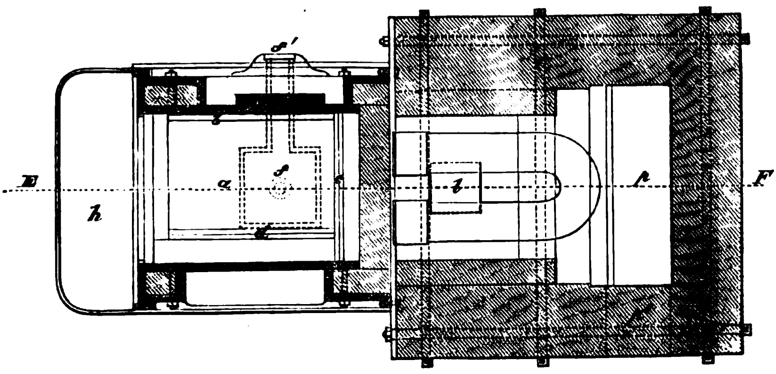

Fig. 120. Swedish Lancashire hearth. Horizontal section on the line A B, fig. 119.

destined to intercept sparks. There is an ash-pit *p*, from which the ashes may be removed through the opening *p*′, which may be closed with a cast-iron door or otherwise.

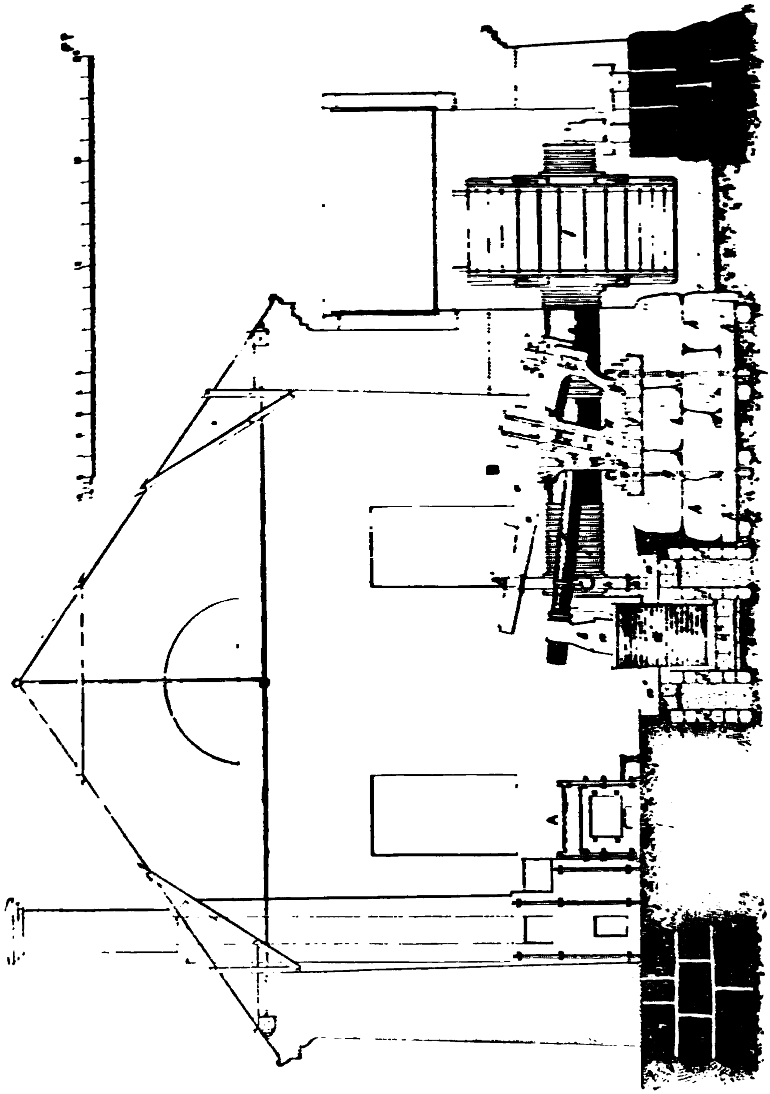

Fig. 121. Vertical cross section of a Swedish Forge.

DESCRIPTION OF A SWEDISH FORGE, WITH LANCASHIRE HEARTH AND HAMMER, FOR DRAWING OUT BLOOMS INTO MERCHANT BARS. FIG. 121.

A. Lancashire hearth as previously described.

B. Anvil and Hammer. Motion is communicated by an overshot water-wheel. The anvil is a solid block of white cast-iron, *a*. It rests upon a wooden block, the anvil block, *a'*, square in section, with the angles rounded off. It is composed of four equal and similar pieces of timber well fitted together with the fibre vertical, and firmly bound with

wrought-iron hoops. The anvil-block is supported on a wooden foundation, consisting of pieces of timber laid horizontally, a''', thus forming an elastic bed and acting as a spring, without which the iron would break on being hammered out into bars. The anvil-block is surrounded by a framework of wood, a'', a'', a'', etc., partly filled in with cinder from the finery stamped solidly down, which is indicated by the dotted shading.

The hammer-head, b, is of wrought-iron; it weighs about 7 cwts., is raised to the height of 2 ft., and gives about 100 blows per minute. The shaft, c, is of birch wood (*Betula alba*), and is cylindrical. One end of it carries the hammer-head and the other moves on trunnions, as shown at d'', in a cast-iron frame, which consists essentially of two equal and, with the exception of certain minor details, similar pieces, set vertically and parallel to each other, and to the shaft of the hammer: one of these side-pieces is shown at d, d. The trunnions, which are of wrought-iron, work in cast-iron blocks, one of which is a fixture on the inside of one of the side-pieces of the frame, while the other, d''', is moveable on the inside of the other side-piece, which is shown in the engraving; this block may be fastened at the upper end by means of wedges between two projecting pieces. This arrangement is necessary in order to facilitate the renewal of the hammer-shaft when it is worn out, which occurs at the end of about every third month. Above the hammer-shaft there are two wooden beams, e, e, of fir wood about 14 in. square: their back ends are fixed in a cast-iron key, e', having on each side a projecting trunnion-like piece inserted into the corresponding side of the frame, d, d; e^{v}, e^{v} are wedges, and e^{vi}, e^{vi} are bolts. These beams act like springs, preventing the hammer from being thrown up too high, and quickening its fall. At e''' is another cast-iron key, similar to the former, except being open at the top, to act as guides for the spring-beams, e, e. These beams are encircled by two strong bands of iron, e'', e'', e'', e'', with cast-iron blocks at the top and bottom. On the under side between the key and block is inserted a packing of deal boards, which may be taken away or introduced through a hole, e^{iv}, and which also serves as a spring. The frame, d, d, rests on a wooden bedding, f, f, f, supported on stonework; and it is fastened down by strong bars of iron, g, g, to a framework of timber at the bottom, h', h'. Transverse wrought-iron bolts are shown at g', g', g'. The shaft, i, i, of the water-wheel, l, is strongly bound with wrought-iron hoops. The hammer is moved up and down by four cams, k', k', k', etc., on the shaft of the water-wheel, as shown at k.

In some localities hammers like those in use at tin-plate works in this country have been recently introduced into Sweden.

Manipulation.—All being in working order and the ball obtained in the last heat removed, etc., charcoal dust is spread out on the fore-side and the hearth is filled with clean charcoal. The pig-iron, which is in plates 2 in. or 3 in. thick and has been previously heated on the plate in the flue, is transferred to the hearth, the charge being 200 lbs. Fresh charcoal is added and the blast turned on, when, in about half an hour, the metal will have completely melted down, and in dropping

through the blast from the twyer have become partially oxidized. By the action of the oxide of iron thus formed, and of the basic silicate of protoxide of iron remaining in the hearth at the close of the last operation upon the molten pig-iron, the latter is decarburized to a considerable extent, and, in consequence, becomes less fusible and more pasty. After perfect fusion of the metal, the refining proper begins. This consists in incessantly breaking up the metal with an iron bar, and carrying towards the twyer the raw portions, which, being more highly carburized and more fusible than the rest, always run down to the bottom, and there harden. The metal, which has thus more or less solidified, is broken up and submitted to the action of the blast until all is sufficiently refined: this operation lasts about half an hour. Subsequently all the metal is brought up to the top of the hearth and again melted down with a lively heat to form the ball, fresh charcoal being thrown into the hearth and the unmelted portions being kept up at intervals with an iron bar to prevent their adhering to the ball before having been melted. The ball is then taken out, and hammered into a prismatic shape, which is cut into pieces to be welded in another fire. The whole process lasts from 1¼ to 1½ hour.

According to Mr. Grill the chief advantages of this method are, that the rawer portions of the metal melt down in drops or liquate, and so separate from that already refined; and in thus liquating it becomes exposed to the oxidizing action of the blast and more or less decarburized, the refined metal remaining aloft all the while. The whole mass of metal is properly and equally refined; and in the final running down into a coherent lump, the slag separates from the iron, and, if present in an injurious degree, may be tapped out. By this means a sound bloom, free from intermixed impurities, is obtained, which, Mr. Grill asserts, is not the case in the puddling process.

The blast is frequently used at a temperature of 100° C., and at a pressure of 2½ in. of mercury.

The cut up pieces to be drawn out under the hammer are welded and heated in hearths much resembling in size and construction the charcoal finery itself; but the furnace now most extensively used for this purpose is the gas-welding or reheating furnace invented by Mr. G. Ekman.

The following details of the average yield and consumption of charcoal in this process in Sweden have been supplied by Mr. Grill :—

Average yield of blooms from one finery per week	6·6	tons.
Weight of bloom per cent. of pig-iron	86·75	"
Charcoal consumed per ton of blooms, by weight	0·9	ton.
Do. do. do. by volume	255	cubic feet.

The blooms are drawn out into bars by one of the three following methods :—

I.

In a reheating forge, with one hammer:

Average make of finished bars per week	6·6	tons.
Weight of finished bars per cent. of blooms	95	"
Consumption of charcoal per ton of finished bars, by weight	1	ton.
Do. do. do. by volume	297	cubic feet.

II.

In a gas-welding or reheating furnace, heated by charcoal, and with two hammers:

Average make of finished bars per week	22·2	tons.
Weight of finished bars per cent. of blooms	86	„
Consumption of charcoal per ton of finished bars, by weight	0·6	ton.
Do. do. do. by volume	170	cubic feet.

III.

In a gas-welding furnace, and by rolling instead of hammering:

Average make of finished bars per week	58	tons.
Weight of finished bars per cent. of blooms	92	„
Consumption of charcoal per ton of finished bars, by weight	0·375	ton.
Do. do. do. by measure	106·3	cubic feet.

It is asserted by Mr. Grill that the Lancashire method yields an excellent iron, and that nearly all the Swedish bar-iron, except the Dannemora or Öregrund-iron, consumed in Sheffield for converting into steel, is made by this method. Sometimes this iron is exported in the form of blooms (billets) only welded and hammered once or twice. Piling iron made by this process is not resorted to. The iron destined for the English steel market is commonly drawn out under hammers moved by water-wheels. For other markets the iron may be rolled. In Sheffield the prepossession is strong in favour of hammered bars; but some steel makers have at length abandoned their prejudices against rolled bars. The only influence which the mode of drawing out, whether by hammering or rolling, can have, is of a mechanical nature; but no such influence can be perpetuated after the conversion of the bars and their subsequent fusion into cast-steel. Mr. Grill is of opinion that the prepossession above-mentioned is due to the fact, that consumers do not distinguish between rolled and puddled iron, and rolled but charcoal refined iron, and conclude that rolled iron necessarily implies puddled iron.

The history of the introduction of the so-called Lancashire process into Sweden is interesting. I am indebted for the following details to Mr. F. C. Wærn, of Gothenburg, son of the Mr. Wærn referred to. Many years ago frequent demands having been made by the Sheffield steelmakers for better manufactured and sounder iron than such as was usually produced at that time by the Walloon method, Mr. C. F. Wærn, of Baldersnäs, in Sweden, and Mr. Brändström, of Hull, in 1829, took over to Sweden workmen from South Wales, skilled in the manufacture of iron for charcoal plates. There were five families, of which the principal was that of Houlder, with three sons and a son-in-law, named Whittington, all excellent workmen. With the aid of these men the process was successfully established at Bâckefors, in Sweden. The Board of Swedish Ironmasters, on hearing of this success, and having been long desirous of adopting a more economical process than the old Walloon method, obtained Mr. Wærn's consent that Mr. G. Ekman should visit his works and master the details of the newly-imported process. The workmen were at first somewhat jealous of what they considered their

works, but soon became on good terms with Mr. Ekman, and communicated everything to him. Mr. Ekman reported that this new method was just the very thing which he and others employed by the Board of Ironmasters had been trying to arrive at, by sundry alterations in the Walloon method. Mr. Ekman introduced the method at his own Works at Lesjöfors, at other Works at [illegible] in which he had shares, and at Works at [illegible]. It was also introduced at the [illegible] Works.

The Norwegian Ironmasters, by the offer of higher wages, bribed most of the English workmen to desert Mr. Warn, and secured their services; but old Hinchliffe and one of his sons remained to the last, and this son is still in the employ of the present Mr. Warn. The conduct of these Norwegian gentlemen would be stigmatised in this country as at least very shabby; but there are unhappily plenty of Englishmen who would not scruple to do likewise.

For about 17 years the above-mentioned works were the only ones, an impression being general in Sweden that if the quantity of such iron were increased the price would soon be reduced to that of common iron; but then it was suddenly taken up by many iron-masters, and is now general.

Professor Tunner, in his most elaborate work on the Production of Wrought-Iron and Steel in the Charcoal Finery by various methods, describes, under the title "Die englische Wallonschmiede," two modifications, which he pronounces to be essentially different, partly on account of the nature of the pig-iron employed, and partly on account of the quality of the wrought-iron produced.[5] These are designated according to locality the Lancashire and South Welsh processes. Now, it is a little singular that the Swedes, who imported the process from South Wales into Sweden in 1829, should term it the Lancashire process. At present, I do not know the reason of this appellation. I have met with a description of the process of making malleable iron in Lancashire direct from the ore in a hearth apparently more primitive than that of the Catalan Forge. It was communicated in 1675 to the President of the Royal Society, Dr. Martin Lister, and published in the Philosophical Transactions in 1693.[6] It is as follows:—

"Thurnham, Sept. 25, 1675.

"SIR,—I send now at last the promised parcels of Iron Ore; one sort of it seems to be good *Hæmatites*. It seems I either did not rightly apprehend, or was not clearly enough informed by the person from whom I had the account I sent you, of the furnace in which they melt down their Oar (*sic*).—It is very much like a common blacksmith's, viz., a plain open hearth or bottom without any enclosing walls, only where the nose of the bellows come in through a wall there is a hollow place (which they call the furnace) made of iron plates, as is also that part of the hearth next adjoining. This hollow place they fill and up-heap with charcoal, and lay the oar (broken small) all round about

[5] Stabeisen- u. Stahlbereitung in Frischherden, 2. p. 161.

[6] Phil. Trans. No. 199, vol. 17, p. 695. April, 1693.

the charcoal upon the flat hearth, to bake, as it were, or neal and thrust it in by little and little into the hollow, where it is melted by the blast. The glassie *Scoriæ* run very thin, but the metal is never in a perfect fusion, but settles as it were in a clod, that they take it out with tongs, and turn it under great hammers, which at the same time beat off (especially at first taking out of the furnace) a deal of courser *Scoriæ*, and form it after several heats into bars. They use no limestone or other thing to promote the flux, for that I enquired particularly."

The Walloon Process.

This is an ancient method, which is still extensively practised. To the English steelmaker it is interesting from the fact of its being employed in the production of the renowned bar-iron of Dannemora, in Sweden. It derives its name from the people with whom it probably originated, the Walloons or inhabitants of Flanders, whence it is reported to have been introduced into Sweden by De Geer in the time of Charles XII.[7] The mode in which it is conducted varies somewhat in different localities. Tunner describes four modifications of it, namely, the Eifler, the Swedish, the English, and the Styrian; and the English he subdivides into the Lancashire and South Welsh methods.[8] But his definition of the Walloon process is wanting in logical precision. Thus he writes: "In the majority of cases, the fining proper [*i. e.* the conversion of the pig-iron into malleable iron] and the further necessary welding process are carried on in one and the same hearth. However, under special circumstances there is either a partial or complete separation of the two processes. The term Walloon is applied to all finery methods, in which the above-named processes are separated." The Swedes draw a broad and, in my judgment, proper distinction between the Walloon and South Welsh, or, as they designate it, Lancashire process; but on this point the reader will be able to form his own opinion after comparing the descriptions of these methods with each other. Some writers on this branch of the metallurgy of iron seem to have been smitten with a love of over-refinement. At all events, they have assigned to unessential differences of manipulation a remarkable degree of importance, and have founded classifications thereon which are hardly admissible.

The Walloon Process, as conducted in Sweden.

According to Mr. Grill, this process has held its ground for the Dannemora iron from a fear lest the adoption of any other less expensive might not yield metal of equal quality, and keep up the long established reputation of its producers.

The hearth is composed of cast-iron plates. The bottom plate is 2 in. thick, and underneath is a strong bed of pounded slag about 3 in. in depth, which rests upon a cast-iron box provided with suitable channels

[7] Rinmann, Geschichte des Eisens, 1. p. 337.
[8] Stabeisen-u.-Stahlbereitung, 2. p. 148.

by means of water. The twyer side-plate inclines somewhat into the hearth, and the opposite side-plate, on the contrary, considerably outwards. From the centre of the twyer to the back-plate the distance is from [illegible] in. to [illegible] in., and to the commencement of the work-plate it is from [illegible] in. to [illegible] in. The front of the hearth is enclosed by a brick wall, [illegible] inclining outwards, and on the top of which the work-plate lies horizontally. This wall is a little higher than the back-wall, and has no orifice any tapping-hole, as the slags are never let out. From the twyer side-plate, on a level with the twyer, the distance to the opposite side-plate is from 22 in. to 24 in. The axes of the twyer and blast-pipe are at right angles to the twyer side-plate, and as this inclines forwards a few degrees into the hearth, they have the same inclination. The nozzle of the twyer is semicircular, with the flat side at the bottom; it is from [illegible] to 25 lines broad, from [illegible] to 17 lines high, and projects ½ in. from the twyer side-plate. The nozzle of the blast-pipe is likewise semicircular, and is somewhat larger than that of the twyer, so that it lies back within the latter 4 in. The depth of the hearth under the twyer is from 7 in. to 8 in., under the upper edge of the back-plate from 14 in. to 15 in., and under that of the work and adjoining side-plate, opposite the twyer, from 15 in. to 1[illegible] in. The fuel is fine charcoal, and this hearth works extraordinarily hot as compared with all others.* Cold-blast is used.

The iron employed is white or strong mottled, and is in long pigs about 9 in. broad, from 15 ft. to 18 ft. in length, and from 3 in. to 4 in. thick at one end, and from 1 in. to 2 in. at the other. The pig is placed at right angles over the back-plate, with one end inclining downwards over the twyer; and as this end melts, the pig is gradually pushed forward so as to keep the end in the same position. Usually two such pigs are put one over the other.

The fore part of the hearth being filled with moistened small charcoal (*Lösche*), and the remainder with charcoal, the fire lighted and the blast let on, the pigs are pushed forwards; and in order to produce a sufficient bath of slag, or, as the Germans expressively designate it, "fire sap," some large finery-scraps (Frischbrocken), or, failing these, several shovelfuls of hammerslag, are melted down.

A peculiarity of the Walloon process in question is that at the beginning of a heat, the bloom obtained from the last lump is held with tongs, as steeply inclined as practicable, in the fore part of the hearth, and reheated preparatory to further manipulation.

The working with the iron bar or staff commences immediately after fusion of the first portions of the pig-iron, and is regularly continued until the whole of the metal melted down on the twyer side has been once brought up from the bottom and that side towards the middle of the hearth, and so exposed to the action of the blast. It is also worked once to the left and once to the right of the bloom undergoing reheating. The melting of the pig-iron takes place pretty

* This and much of the following description is nearly a literal translation of that given by Tunner, Stabeisen-u.-Stahlbereitung, 2. p. 155. Vid. also Eisenhüttenwesen in Schweden, p. 68.

quickly, about 70 lbs. being occasionally melted in 20 minutes. Owing to the facility with which this kind of pig-iron "comes to nature," *i. e.* arrives at the state of malleable iron, and the continual working with fresh staffs, the metal which has been fused is by that time so far refined that thin pieces of malleable iron will be seen adherent to the staff. The whole of the molten metal is now completely broken up above the twyer, melted down, and formed into a lump; and during this part of the process the supply of fresh molten pig-iron from above should obviously be stopped. The lump is about 12 in. broad, and 15 in. long. The average period between the completion of one lump and another is 28 minutes, the extremes being 25 and 30 minutes. Each lump is heated from 6 to 8 times in the course of being drawn out into a bar 12 ft. long, and the weight of the bar from each lump is about 60 lbs. The shift lasts 8 hours. Two finers and one assistant are required for each hearth.

It is evident that in this process the pig-iron is exposed to conditions favourable to rapid decarburization by oxidation, namely, the small quantity of iron operated on at a time, the comparatively large size of the hearth, the high temperature, the large amount of blast, the gradual melting of the pig-iron drop by drop before the blast, and the almost incessant working of the metal.[1] Mr. Grill gives the following summary of the distinctive features of the Walloon process, as practised at Dannemora:—1st. The large, long pigs introduced with one end in the hearth, thereby allowing fresh pig-iron to melt down during the whole period of refining. 2nd. The "dry," "hot" process, which does not permit any slag to be let out, although much hammerslag is actually added. 3rd. The reheating of a bloom from a former operation in the hearth during the first period of melting. 4th. The large area of the twyer, and the small weight of the bloom, about 100 lbs. (Tunner says less). 5th. The drawing out of the bloom under hammers moved by water-power, after having been repeatedly heated in a *separate* fire. It is well remarked by Mr. Grill, that, so far from this process contributing in any degree to the excellence of the Dannemora iron, the very contrary is probable; and that that excellence is due exclusively to the superior quality of the Dannemora ores.

Mr. Grill has furnished me with the following details of the yield and consumption of charcoal by this process at Dannemora, from one finery, one drawing-out forge, and one hammer:—

Average yield per week of finished bars				6 tons.
Weight of bar-iron per cent. of pig-iron				80 „
Charcoal consumed per ton of bars, by weight				3 „
Do.	do.	do.	by volume	893 cubic feet.

Tunner describes with great minuteness, and with, I doubt not, equal accuracy, the Walloon process as conducted in the Eifel district in Rhenish Prussia; and there does not appear to be any essential or important difference in the mode of proceeding in that locality and at Dannemora.[2] The Eifel wire, which is reported to be highly esteemed,

[1] Tunner, Op. cit. p. 159. [2] Op. cit. 2. p. 148.

is made from iron produced by this process. The same author also describes what he designates the Styrian Walloon process, but there is nothing in the description to induce me to notice it particularly in this work.[3]

The Franche-Comté Process.

Franche-Comté is the name of an old province in the east of France, having Besançon for its capital town, but which is now divided into the departments of Doubs, Haute Saône, and Jura. The method now to be described has acquired its designation from having been long practised, if not originated, in that locality, whence it was imported into Germany and Sweden.[4] It is termed by the French "Méthode Comtoise," and is the prevailing charcoal finery process both in France and Belgium. One of the best accounts which I have met with is that of Thirria; and of this I shall chiefly avail myself in the following description, translating literally, as far as practicable.[5]

The hearth is composed of five cast-iron plates, and is nearly rectangular. The twyer side-plate is termed the *varme*, the opposite side-plate the *contrevent*, the back-plate the *haire*, the fore-plate the *chio* face, and the bed-plate the bottom-plate. All these plates are rectangular, except that of the twyer-side, which is occasionally not so high on the side of the back-plate as on the side of the fore-plate, in order that when there are two twyers the hind one may be set a little below the front one. The fore-plate is from 0^{m}02 to 0^{m}03 (0·79 in. to 1·18 in.) thick, and the others from 0^{m}06 to 0^{m}07 (2·36 in. to 2·76 in.) thick. They last during several months, except the bottom-plate, which must be renewed every week and sometimes more frequently; but the hearth is so constructed that this renewal may be effected by simply taking down the fore-plate.

The hearth should rest on a brick or stone foundation, covered with a layer of clayey soil well beaten down; and if there is danger of moisture, this may be completely avoided by setting it in a cast-iron box. In order to prevent the bottom-plate from becoming too hot, in which case the fining process would be retarded, it is placed on a little frame of iron 0^{m}5 (1 ft. 7·69 in.) long, by 0^{m}2 (7·87 in.) broad, and 0^{m}0·27 (1·07 in.) thick, so that by means of an old twyer a little water may be made to flow into the space between this plate and the ground; but this should not be done until just after the lump has been taken out, for otherwise the great heat of the hearth might crack the plate.

The back-plate is set between the twyer side-plate and the opposite one, and the fore-plate also rests against these two plates, but standing upon the bottom-plate. The back and fore plates are always fixed vertically. The twyer side-plate is sometimes vertical, and at others slightly inclined towards the interior, especially when it is intended to treat dark-grey pig-iron (*fontes noires*), which only melts at a high

[3] Op. cit. 2. p. 185.

[4] Tunner, Op. cit. 2. p. 207.

[5] Mémoire sur les perfectionnements et modifications des procédés employés pour la fabrication du fer obtenu par l'affinage des fontes dans les foyers d'affinerie. Par M. E. Thirria, Ingénieur en chef des Mines. Ann. des Mines, 1840. 3. s. 18. p. 215 et seq.

temperature; this inclination bringing the blast closer to and concentrating the heat upon the pig, which is pushed forward as in the Walloon process. The side opposite the twyer is formed either of a single piece, always a little concave, or of two pieces of cast-iron, one supported upon the other, the upper one resting upon a little brick wall, and the lower one forming with it a very obtuse angle. Almost always this side leans a little inwards, in order to prevent loss of heat; sometimes it is quite vertical; and rarely it leans a little outwards, so as to facilitate the withdrawal of the lump when of very large size. The bottom-plate is inclined both towards the side opposite the twyer and the fore-plate—an arrangement which is essential in order that the cinder may flow easily through the tap-hole situated on the twyer-side. This double inclination is given by means of small pieces of iron placed at the angles of the plate, or under the little frame on which it rests. The various plates are fixed most solidly together with little wedges of iron.

Some hearths are blown with one (according to the old practice), and others with two twyers. Thirria recommends two twyers, as every way preferable, especially on the ground of economy of fuel. The twyers are of copper, and last 9 or 10 months. With hot-blast cast-iron water-twyers are employed; but when the temperature of the blast does not exceed 200° C., copper ones may still be used, although they require more frequent renewal than with cold-blast. The muzzle or "eye" of the twyer is semicircular, 0^m027 (1·07 in.) by 0^m024 (0·95 in.), when the hearth is blown with two twyers, and 0^m040 (1·58 in.) by 0^m027 (1·07 in.) when only with one. The "eye" has been recently (1840) made very flat, 0^m040 (1·58 in.) long by 0^m010 (0·39 in.) high, in order to compel the blast to spread in a sheet, and this has been attended with advantage. When there are two twyers they touch each other outside the hearth, but in the interior they are a little separated. Whether there are two twyers or one only, the blast always enters the hearth through two cast-iron blast-pipes, of which the "eye" is circular, and from 0^m024 (0·95 in.) to 0^m026 (1·03 in.) in diameter.

In recent times most of the hearths have been covered, either with an arched roof destined to prevent loss of heat, or by a flue conducting the waste flame into a lateral oven (*four*), where it is utilized; and this arrangement has caused a notable economy of fuel.

Certain changes are made in these hearths according to the quality of the pig-iron to be treated; and they consist chiefly in increasing or diminishing the depth of the fire, the inclination of the blast, and the projection of the twyers into the interior.

Large grained grey pig-iron, with graphitic scales, is usually treated by this method, and only occasionally mottled and white pig-iron. All the pig-iron consumed is made from pisolitic iron-ores, occurring either in the upper tertiary beds, or in deposits derived from those beds, and yielding from 33% to 36% of pig-iron.

Manipulation.—The pig-iron is supplied to the hearth exactly as in the Walloon process, and gradually melted, the molten metal trickling

down as it goes through the strongly oxidizing blast. After the removal of the lump or ball in the last heat, the rich cinder (scories) which may have accumulated at the bottom is raised up; the bottom (to use an expressive word in common use amongst English workmen) is well "fettled" with small charcoal; and the pig is then pushed forward over a roller, with one end inclining somewhat downwards. The pig ought to be so placed that the distance between it and the side facing the twyer is only [illegible] or 0m·04 (1·5[illegible] in.), in order to promote as much as possible the action of the blast upon the pig-iron, allowing it, however, to ascend to the top of the fire. The bottom of the pig also should be 0m·1 [illegible] or 0m·12 (4·7 in.) above the stratum formed by the blast, and its extremity should not be more than [illegible] (2·[illegible] in.) beyond the axis of the twyer in front. In this position the pig melts drop by drop, and this is essential to success.

Before filling up the hearth with charcoal, pieces of rich cinder (scories), intermixed with hammer-slag, are placed upon the pig on the side farthest from the twyer. These slags, which quickly melt, are destined to form a bed upon which the metal dropping from the pig, during the whole period of fusion, should rest, as well as the bath of poor slag, which ought to cover the product of that fusion, and preserve it from the action of the blast. Moreover, when the hearth has been filled with charcoal a shovelful or two of hammer-slag is thrown on the top. A finery of this description, when in good working order, consumes all the rich slag which it produces, only the poor, containing about 60% of protoxide or 46% of metallic iron, being thrown away.

The ball is shingled or forged under the hammer into a bloom which is cut into two equal and similar pieces, which I will designate as Nos. 1 and 2. No. 1 is placed in the fire between the pig and the twyers, so that its end plunges into the bath of cinder covering the metal which has melted down, but without touching the metal itself, of which the contact would produce cementation, and render the piece brittle. No. 2 is put upon the twyers and covered over with charcoal, and there remains until the first part of the forging of No. 1 is completed. The heating of No. 1, which the forgeman turns about from time to time in the bath of cinder, in order to heat it uniformly on all its faces, requires about 15 minutes; and as soon as it is out of the fire No. 2 is put in its place. No. 1 is drawn out under the hammer to the extent of half its length, into a bar of the required dimensions, but somewhat larger at the extremity which is termed the bar-end; and the bar part is then plunged into water until it is cold enough to be handled; after which the undrawn-out or thickest end, which for the sake of distinction I will term the head, is introduced into the fire so as to rest upon the twyers. No. 2 having now become white or welding hot, which occurs after heating for about 10 minutes in the middle of the fire, it is replaced by the head of No. 1; and when it has been treated in all respects like No. 1, as above described, its head is placed above the twyers until the thick end of No. 1 has been removed. The latter, after about 15 minutes' exposure to a sweating heat, is forged into a bar and bar-end. Afterwards the bar-end is put in the fire by

the side of the head of No. 2, which, after a heat of about 15 minutes, is drawn out in the same manner into a bar and bar-end. These different forgings being completed, it only remains to forge the four bar-ends, of which the heating requires about 20 minutes, so that it needs about 1½ hour at most to heat all the pieces intended for forging.

During this first part of the process the forgeman has only the following duties to perform: regulate the blast by means of a register above the blast-pipes; supply charcoal to the fire; open one of the two tap-holes in order to let out the excess of cinder,—the lower one when the cinder melts easily, and the upper one in the opposite case; add hammer-slag to replace the poor cinder tapped off; order the pig to be pushed forward whenever necessary; throw into the fire either a little quartz or clay, if the cinder is deficient either in quantity or fusibility; sound the fire at intervals with an iron bar, to ascertain the condition of the cinder as well as that of the lump in process of formation; and to sprinkle water on the front of the fire, in order to protect himself from too great heat, and prevent the small charcoal from being carried away by the blast.

Immediately the last piece to be forged is taken out of the fire, the pig is drawn back, so as to prevent it from melting, and then begins the second part of the process, or the "work," as it is termed by the French. The first object of the forgeman is now to bring up above the mass of iron destined to become the ball, the pieces of rich hardened cinder (*sornes ou scories endurcies*) between it and the bottom of the hearth. In order to this he raises them with an iron bar, and places them in the angles and along the edge of the fire-plate containing the tap-holes. He then draws them upon this plate by means of an iron hook, and separates from them the adherent ferriferous portions to be put back into the fire. This first operation, termed "desornage," lasts about 5 minutes.

The forgeman then raises the ferriferous mass above the level of the twyers, in order to expose the different parts of it to the decarburizing action of the blast, which is done in about 20 minutes. When the half-refined iron has redescended upon the bottom, with which it has been in direct contact since the "desornage," the forgeman pierces it with his bar in order to ascertain which portions of it require further exposure to the blast. Those which adhere only feebly to the bar must be again subjected to the decarburizing action of air, whilst the iron portions which adhere strongly to it, and which he cannot detach from the bar without striking on it with a hammer, must be protected from the blast and, with this view, placed either against the back-plate, or towards the plate facing the twyer. This operation requires only about 5 minutes, so that the whole period of the "work" lasts about half an hour. The forgeman, moreover, promotes the depuration of the metal by throwing into the fire at repeated intervals hammer-slag and the pieces of iron detached, as above stated, from the bar. The hammer-slag, especially, contributes to the complete decarburization of the pig-iron by the oxygen of the protoxide of iron, of which

that slag chiefly consists, yielding oxygen for the combustion of the carbon, with the reduction of an equivalent proportion of iron. During this second stage of the process the mass of iron presently to become the ball is nearly always uncovered, and the blast, which is full on, produces at the surface of the hearth brilliant scintillations, composed of particles of molten cinder and incandescent charcoal.

The third and last stage of the process is termed "avalage," or balling process. It consists in collecting together by means of the bar all the pieces of decarburized iron, and forming them into a ball in the centre of the hearth. With this object, after having reduced the blast, the forgeman separates with his bar the "sornes" and small charcoal which may hinder the agglomeration of the pieces of iron. He then forms the ball by uniting these pieces successively to a kernel situated towards the middle of the bottom-plate, taking care that the blast does not reach it. All this is effected in 15 or 18 minutes. The process is completed by throwing over the top of the ball a shovelful of hammer-slag, in order to cool it and to cause it to acquire a suitable consistency for removal from the fire. That done, about 20 minutes having elapsed since the beginning of the "avalage," the two forgemen take out the ball, first by raising it with iron bars, and then drawing it with hooks over the tap-hole side.

Thirria gives the following table, showing the variations in the volume of the blast during the three stages of the process, and the time occupied in each.

	Stage of the Process.	Volume of air injected, the volume maximum being represented by 100.	Duration of the action of the volume of air injected.	
			Minutes.	
Melting down of the pig-iron and re-heating of the iron from the last process	At the beginning of the process...........	40	10	85
	In the heating and first drawings out of Nos. 1 and 2...........................	45	25	
	During the forging of the head of No. 1	50	15	
	Do. do. No. 2	60	15	
	In the heating of the bar-ends to be forged	75	20	
"Work," or raising up before the blast	During the "desornage"	75	5	30
	During the "work"................	100	25	
"Avalage"	During the "avalage," properly so called	75	10	20
	During the formation of the ball	60	7	
	When the hammer-slag is thrown upon the ball	40	3	
	Mean	65	Total 135	

Yield and consumption of materials.—The ball, obtained in 2¼ hours, usually produces in shingling, *i. e.* hammering into the bloom, from 80 to 85 kilogrammes of Nos. 1 and 2; and in forging, from 65 to 70 kil. of iron in bars, the loss in forging varying from 15% to 18%, according to the dimensions of the bars manufactured. The consumption of pig-iron varies from 92 to 96 kil. per ball, or from

1330 to 1370 kil. per 1000 kil. (about 1 ton of 2240 lbs.) of iron obtained.

The consumption of charcoal depends upon its quality and the dimensions of the iron manufactured, the iron forged into small pieces requiring to be heated longer than that forged into large ones. The best charcoal for the purpose is that of hard woods, such as beech, hornbeam, and oak; but the first two are preferred to that of oak, and particularly to the charcoal of white wood, which produces, perhaps, somewhat softer (*plus doux*) iron, but with a consumption of 15% or 20% more. In the new (1840) covered-in hearths, 0·085 cubic metre is required for each ball, or on the average 7 cubic metres per 1000 kil. of iron of various sizes. Of this about ¾ are consumed in the fusion of the pig-iron and the reheating of the iron during forging, and only ¼ in the second and third stages of the process. According to Richard the average weight of a cubic metre of charcoal is 222 kil.[6] For the ton of bar-iron, therefore, the consumption in this process of charcoal by weight is 1554 kil., or about 1½ ton.

Mr. Grill informs me that, in his opinion, the Franche-Comté process is the most economical of all, produces very good iron, and is far superior to the old German method, which is almost extinct in Sweden; and from him I have received the following details of the average yield and consumption of charcoal by this process in Sweden, in one finery and with one hammer:—

Yield per week of finished bars	3·7	tons.
Weight of bar-iron per cent. of pig-iron	85	„
Charcoal consumed per ton of bars, by weight	1·5	ton.
Do. do. do. by volume	425	cubic feet.

According to Thirria a Franche-Comté finery requires a staff of 6 workmen, 3 at each turn of about 8 hours, during which 4 balls are made. The three men working at a turn are 2 forgemen and 1 assistant. One of the forgemen is termed the *finer*, and the other the *hammer-man*, who attends to the hammer; but most frequently this man is also at the same time finer. The two forgemen on duty make balls alternately, and each forges his own ball. The forgemen were paid by piece-work, at the rate of 16 francs per 1000 kil. of *large* iron (*gros fer*), and 18 francs per 1000 kil. of *small* iron (*petit fer*), and each usually received 10 francs per month in excess of the wages of manufacture. As a Franche-Comté finery ordinarily produced 18,000 kil. (about 18 tons of 2240 lbs. to the ton) of large iron, or 16,000 kil. of small iron, the finer and hammer-man gained from 80 to 85 francs per month, and the other two forgemen 70 to 75 francs each per month. The assistants were paid by the month, and gained from 18 to 20 francs each in that time.

Cost of production.—The statement of Thirria underneath refers, it must be borne in mind, to the year 1839; but it is, nevertheless, interesting, and with changes in accordance with present prices might be made applicable to the present day.

[6] Etudes sur l'Art d'extraire le Fer, etc., p. 5.

Cost of producing 1000 kil. of iron of medium sizes by the Franche-Comté process in one finery, yielding 170,000 kil. (about 170 tons of 2240 lbs. to the ton) per year:

			Francs.
Pig-iron (1350 kil., at 195·04 francs the 1000 kil.)			263·30
Charcoal (7 cubic metres, inclusive of waste, at 20·95 francs)			110·35
Labour			21·50
Water-course (2500 francs per year)	14·70	60 francs.	60·00
Interest on capital (30,000 francs per finery at 6 % = 1800)	10·58		
Management, repairs, contributions, and sundry expenses	34·72		
Total			485·15

The cost of production was therefore about 19*l.* per statute ton of 2240 lbs.

In treating dark grey, highly graphitic pig-iron, which melts less easily than grey pig-iron, but which, when once fused, remains longer liquid, the following alterations, according to Thirria, are made:—1. The blast is inclined so as to produce the highest temperature in the upper part of the fire, *i. e.* from 7° to 8°. 2. The twyers are advanced 0^m 10 (3·94 in.), instead of 0^m 080 or 0^m 090, and the twyer-plate is made to slope a little more than usual towards the interior of the fire, in order to bring the blast nearer the pig, and so facilitate its fusion. 3. The back-twyer is placed 0^m 030 (1·18 in.) or 0^m 040 (1·58 in.) nearer the back-plate, as well to raise the temperature in the posterior part of the fire, where the pig is, as to render more easy the raising up of the ferriferous mass. 4. The depth of the fire, which is usually 0^m 20 (7·87 in.) for grey pig-iron, is increased to 0^m 230 (9·05 in.), an arrangement from which it results that the drops from the melting pig fall through a longer course, and the temperature in the lower part of the hearth is lowered, whereby the coagulation of the ferriferous mass is promoted. 5. If practicable, the volume of the blast injected during the different stages of the process is increased, and chiefly at the time of raising up the ferriferous mass. 6. More rich cinder is added, in order, by means of the oxygen which it contains, to promote the decarburization of the metal. 7. The ferriferous mass is exposed more, and during a longer time, to the action of the blast, a more efficient means of decarburization than the addition of rich cinder.

In treating white and mottled pig-iron, which melt more easily than dark grey and grey pig-iron, but which in a state of fusion are less liquid and congeal more promptly, *cæteris paribus*, it becomes necessary, on the one hand, that their fusion should not take place too rapidly, as, in that case, they would form a *magma* in the hearth, without being sensibly decarburized; and, on the other hand, that the ferriferous mass should not coagulate too quickly, which would produce imperfectly depurated iron. Consequently, the following alterations are made:—1. The inclination of the blast is less than 7° or 8°, which produces the maximum temperature in the part occupied by the pig, and is reduced to 3° or 4°. By this means the white or mottled pig-iron does not, like the dark grey and grey pig-iron, melt drop by

drop, but in little scales (*petites écailles*), which is requisite, in order that it should not be too much decarburized in its course from the pig to the bottom of the hearth. 2. The twyer-side is fixed vertical, and the twyers are only advanced 0^m 050 (1·97 in.) or 0^m 060 (2·36 in.), instead of 0^m 080 or 0^m 090, so that the pig may be less exposed to the action of the blast. 3. The front twyer is brought 0^m 030 (1·18 in.) or 0^m 040 (1·58 in.) within the fore-plate, in order to lower the temperature in the posterior part of the hearth where the pig is. 4. The depth of the hearth is diminished to 0^m 170 (6·7 in.) below the eye of the twyer, with the double object of rendering the decarburization of the pig-iron less complete in its course to the bottom of the hearth, and of keeping the ferriferous mass in a pasty state during the whole period of its depuration. 5. The bottom is a little less inclined towards the side facing the twyer, in order that the ferriferous mass may be subjected to a higher temperature in the vicinity of that side, and its coagulation be retarded. 6. The intensity of the blast is a little diminished during all the stages of the process. 7. Less rich cinder is added, so that decarburization may take place with all proper gradation. 8. During the raising up stage, the ferriferous mass is exposed for a shorter time to the decarburizing action of the blast.

Thirria describes two modifications of the Franche-Comté process (which I will call A) under the titles of "Méthode Champenoise" (B), and "Méthode Bourguignonne" (C); but there is nothing so peculiar in either as to render any special account necessary. In both the hearth is constructed in the same manner as in A, though the dimensions are smaller, and there are other minor differences, relating to the inclination of the sides, etc. In B mottled pig-iron was usually treated, and in C white pig-iron.

The pig-iron melts drop by drop in A and C, while it ought to melt "in scales" in B. In A and B the ferriferous mass resulting from fusion of the pig is raised up and subjected to the oxidizing action of the blast, but this operation does not last so long in B as in A. In C it is omitted, as the decarburization of the pig-iron is almost completely effected in its course from the pig to the bottom of the hearth. In A much rich cinder is used to promote decarburization, in B little is added, and in C none. In B the end of the melting pig is several times broken off, so that portions of non-decarburized iron may mix with the ferriferous mass and keep it in a pasty state during a suitable time; on the contrary, this is avoided in A and C. In A the ball is larger than in B and C, and is forged into two blooms, whereas only one bloom is made in B and C.

From actual results Thirria arrived at the conclusion that hot-blast might be advantageously adopted in the treatment of cold-blast charcoal pig-iron, with a saving of from 10 % to 16 % of fuel in covered-in fineries, and of from 3 % to 7 % of pig-iron, and with from 8 % to 10 % increase on the yield of iron. The temperatures which he recommended for the blast in A, B, C, were, respectively, 80° to 120°, 130° to 150°, and 160° to 180° (Centigrade).

The following comparative statement by Thirria of the make, con-

sumption of pig-iron, etc., by the three processes, may be interesting:—

	Franche-Comté method.	Méthode Champenoise.	Méthode Bourguignonne.
Duration of the process in minutes........	135′	90′	40′
	kil.	kil.	kil.
Average weight of iron yielded by the ball in each operation	65	48	23
Amount of pig-iron consumed in each operation....................................	88	66	32
Weight of bar-iron manufactured in 24 hours	680	760	840
Average production of finished iron per month	17,000	19,000	21,000
Consumption of pig-iron per 1000 kil. of finished iron	1350	1380	1400
Consumption of charcoal per 1000 kil. of finished iron	cub. met. 7·00	cub. met. 6·85	cub. met. 6·34
	francs.	francs.	francs.
Cost of production of 1000 kil. of finished iron of medium sizes	485·15	435·04	381·46

Slag-bottom Process (*Schwallarbeit*).

This method is practised in Styria. The hearth is similar in construction to those previously described. The bed is composed of rich finery cinder, broken up small, and stamped firmly down; and much attention is required to keep it in good order. The metal treated is cellular white pig-iron (gross-luckiger Floss), which is added in pieces about 7 in. or 8 in. broad, and 1½ in. thick. The charge is about 230 lbs.[7] One ball is produced, which is divided into eight blooms, and each bloom is drawn out into a bar under the hammer. In reheating the blooms they are immersed in the bath of molten cinder. The merchant bars are specially used in the manufacture of nails and wire. The loss is 15 % of the pig-iron treated. The charcoal (pinewood) consumed, per 100 parts by weight of finished iron, is from 23 to 25 cubic feet. A heat lasts from 1½ to 2 hours.

Styrian Process (*Steirische Löscharbeit*).

The hearth resembles those already described. The bed is formed of the small residual charcoal from previous operations, and which contains more or less of intermingled cinder. It is moistened, stamped down, and then shaped into a suitable cavity. The metal treated is large and small cellular white pig-iron, the former (gekrausten Flossen) being adapted to produce hard, and the latter (kleinluckige Flossen) soft wrought-iron. As in the last process, so in this, the fining and

[7] Austrian. I have not considered it necessary to give the corresponding English weights and measures, as, in processes of this nature, the differences are too small to be of any practical importance.

reheating are conducted simultaneously in the same hearth. The metal is added in pieces about 2 in. thick. The charge for hard iron is about 250 lbs., which is introduced in two portions of 150 lbs. and 100 lbs. respectively, at separate stages of the process. The charge for soft iron is about 160 lbs., which is also added in two portions of 100 lbs. and 60 lbs. respectively. The first portion of the charge, previously heated during the second stage of the reheating process, is melted slowly down with the blast not full on, and fusion begins in about 20 minutes. The second portion of the charge, also previously heated, is slowly melted down likewise; and it is so arranged that it shall begin to melt about 10 minutes after the commencement of the fusion of the first portion. From 20 lbs. to 40 lbs. of hammer-slag are thrown in directly upon the surface of the molten metal, previously denuded of charcoal. One ball is made, and is usually formed into four blooms. The loss for hard iron is about 8 %, and for soft iron about 12 % upon the pig-iron treated. The charcoal consumed, per 100 parts by weight of bar-iron, is about from 30 to 40 cubic feet. A heat lasts 2 hours.

Carinthian Process (*Kärntnerische Löscharbeit*).

An interesting point in this process is the form in which the pig-iron is treated, viz. in thin discs (blatteln), resembling in shape those which are obtained in the Continental method of refining copper, described in the First Part. They are produced also in the same manner. They vary from 6 in. to 3 ft. in diameter, and are about ½ in. in thickness, except at the edges, where the thickness is greater. The metal is in the state of white pig-iron, and the discs should be brittle and white on fracture. Before use, the discs are kept heated to redness during a considerable time, say about 30 hours, with pretty free access of atmospheric air, whereby carbon is removed, as in the process of making malleable cast-iron, and superficial oxidation takes place. The Germans designate this operation "Das Braten," *i. e.* "roasting." It is effected in hearths from 10 ft. to 20 ft. long, and 5 ft. to 6 ft. broad, open at the top, and having an air-channel extending the whole length. The discs are piled more or less vertical, and charcoal is used as the fuel.

The fining and reheating processes are conducted in the same fire. The hearth is composed of plates of cast-iron, and presents nothing unusual in construction. During the process of working, the bottom is always covered with a layer of "lösch," from 4 in. to 6 in. thick. The roasted discs are broken, and piled in the hearth in packets from 15 in. to 20 in. long, 8 in. to 10 in. broad, and 6 in. high, the largest pieces being placed at the bottom, and with the broadest side of the packet towards the twyer. Such a packet weighs about 120 lbs. It is then gradually melted down, care being taken to prevent any unmelted portions from dropping into the molten metal accumulated beneath. A second but smaller packet, weighing about 100 lbs., is piled on the top of the first, when the latter is partially melted down; and over the whole are placed small pieces of roasted discs

mixed with hammer-slag. One ball weighing from [illegible] lbs. to 240 lbs. is produced and made into two blooms, which are subdivided into 6 parts each, and hammered out into bars. The loss upon the roasted plates is 2?%. The consumption of charcoal per 100 parts by weight of finished iron is from 25 to 3? cubic feet, exclusive of that consumed in roasting the discs, which amounts to 2 cubic feet extra. A heat lasts about 2½ hours.

Tyrol Process (*Tyroler Schmiede*).

It is stated to be very similar to the Styrian process. Refined pig-iron is treated in charges of about [illegible] lbs. One ball only is produced. In making finished iron the loss of pig-iron is from 23% to 25%. The consumption of charcoal is reported to be from 30 to 40 cubic feet. The fining process lasts from 2 to 2½ hours.

Siegen Process (*Siegensche Einmalschmelzerei*).

The hearth is as usual made of cast-iron plates, and presents nothing remarkable in construction. The bed is formed of a mixture of broken-up cinder and hammer-slag. The pig-iron operated on is mottled or white. It is used in the form of long pigs, exactly as in the Walloon method. The charge varies from 600 lbs. to 700 lbs. The cinder is tapped off during the process. One ball only is produced. The loss in making finished iron is 25% on the pig-iron. The consumption of charcoal is stated by Tunner[a] to be only 6 cubic feet per 100 lbs. of finished iron, but according to Karsten[b] and Wigand[1] it is about 9 cubic feet. A heat lasts about 3 hours.

Lombardy Process (*Müglaarbeit*).[2]

According to Tunner this method was generally practised in Lombardy, and at Primor, Southern Tyrol, and is still occasionally used. Its peculiarity consists in subjecting the pig-iron to a special treatment before the fining proper commences. I shall chiefly avail myself of the paper of Audibert in the following description, translating freely, as far as possible. The process, as conducted at Lecco in the valley of Sassina, comprises three distinct stages:—

1. Slow fusion of the pig-iron under the blast. This is in fact similar to the ordinary refinery process under coke, except that it is carried further. 2. Formation of *cotizzi*, or cakes formed by the agglomeration of half-fined pig-iron, fragments of charcoal, and cinders. 3. Fining proper, shingling, and drawing out into bars.

1. The charge consists of 250 kil., or about 500 lbs., of pig-iron, half from Bergamo and half from Brescia, in pieces about 12 or 14 square inches in area, and 2 in. or 2½ in. thick. The preceding operation ended, the hearth is emptied and cleaned, after which a solid bed of moistened

[a] Op. cit. 2. p. 142.
[b] Eisenhüttenk. 4. p. 146.
[1] Frischhüttenb. p. 56.
[2] Vid. Notice sur l'affinage du fer par la méthode bergamasque dans les usines de Lombardie. Par M. Ed. Audibert. Annales des Mines, 4 s. 1. p. 613.

charcoal-powder is formed in it up to the twyer; it is then filled up with large charcoal, and the blast is turned on. The entire charge is added at once on the top of the charcoal, and as near the twyer as possible. During the whole of this stage, in order that fusion should proceed slowly, the blast is only half on. Every time charcoal is added, what remains of the unmelted pig-iron is raised up and kept at the height of the twyer, so that it may be prevented from falling in a solid state into the liquid stratum at the bottom of the hearth. After fusion of the pig-iron, which is completed in 2½ hours, water is thrown upon the fire, and the charcoal rapidly removed from the hearth. The bath of molten metal is uncovered, and water is then thrown on it in order to solidify the supernatant cinder, of which the greatest part is removed. About 50 lbs. of hammer-slag is next added to the molten metal in three successive portions, and the whole is well rabbled or mixed up together. The metal instantly becomes pasty and collected into clots. It is taken out, placed upon a platform, and cooled with water. It is very important that this part of the work should be done very quickly, without which, the hearth becoming cold in a few seconds from the injection of the water, the solidification of the pig-iron would prove an obstacle to its extraction. This sometimes happens, and part of the pig-iron adheres to the bottom of the hearth, which must be broken with a hammer, and cannot even then be detached without difficulty.

The products of this stage are—1. Cinders taken out of the hearth before touching the pig-iron, which are not subsequently used in fining, and are sold for the blast-furnaces. 2. Half-fined pig-iron, mixed with a certain quantity of cinder, which it was not attempted to separate, fragments of charcoal, and hammer-slag. This mixture is a sort of slightly-coherent breccia.

2. The hearth is cleaned, and again filled with charcoal-dust strongly stamped down, so as to leave no cavity anywhere except in front of the twyer. Into this cavity is charged the sixth part of the mixture of half-fined pig-iron and cinder produced in the first stage. On the top is thrown a shovelful of incandescent charcoal, which is covered with charcoal-dust. The blast is afterwards turned on, but very feebly, and it is forced to spread itself through the whole metallic mass by introducing an iron hook into the twyer in front of the blast-pipe. During this period scarcely any charcoal is consumed. The blast, always injected in very feeble quantity, strikes directly upon the pig-iron, so that only very little of the charcoal, which is below, burns away. The labour of the workman is almost nothing: it consists in piling up with a shovel the fragments of pig-iron, so as to cause them to agglomerate, renewing the layer of charcoal covering them, and moistening it, in order that the blast may be compelled to circulate in the metallic mass as long as possible, and in keeping this mass at the level of the twyer. The temperature rises just sufficiently to solidify the cinder mixed with the pig-iron, and to soften the pig-iron itself, so that the matters not agglomerated at their entrance into the hearth, finish by agglutinating together and forming a cake termed *cotizzo*, to

which the hollow on the exterior produced by the blast gives the form of a cap. When it is judged that the *cotizzo* or lump may be raised in one piece, which usually happens in ¾ hour, the blast is stopped, the fire uncovered, the lump taken out, and placed on a platform near the hearth. A second lump is formed in the same manner, and so also with 4 others, there being 6 in all.

3: Each lump is fined separately in the ordinary way. The process, however, is rendered very easy by the advanced state of the decarburization resulting from the preliminary treatment. The hearth is brasqued with charcoal as in the preceding operation. On the top unignited large charcoal is placed, together with a little incandescent charcoal, and then a lump is put by the side of the twyer. The blast is let feebly on at first, and gradually increased so that it may be full on in ½ hour. Rich cinder and hammer-slag, from a former operation, are thrown on the fire at intervals on the side of the twyer; charcoal is constantly supplied, and at each addition the lump is raised, so that it may always be fully exposed to the action of the blast. The iron comes gradually to nature, detaches itself from the lump by clots (*grumeaux*), which drop with the cinder into the brasque, unite together, and form the ball. An hour is required in this operation. The ball is forged and divided at ⅗ of its length into two blooms. In each heat are produced 3 bars, weighing about 12 or 13 kil. each. The forging lasts an hour. Not less than 18 hours are needed for the fining and forging of the original charge of 250 kil. of pig-iron. The consumption of charcoal is very large, being 240 kil. for 100 kil. of finished iron. The loss is 4½ °/₀ on the pig-iron, *exclusive* of the hammer-slag employed; but *inclusive* of this slag, which usually contains from 70 °/₀ to 75 °/₀ of metallic iron, it is 18 °/₀ or 19 °/₀. This slag is very cheap; and estimating it at its equivalent value in pig-iron, the loss is 8 °/₀. Tunner states the loss to be from 14 °/₀ to 16 °/₀. The cost of production of 100 kil. of finished iron is as follows:—

Pig-iron	105 kil.	24·15	francs.
Charcoal	266 ,,	19·12	,,
Hammer-slag	21 ,,	0·84	,,
Labour		1·87	,,
		45·98	

That is, somewhat more than 18*l.* per ton; but this does not include general expenses, such as interest on plant, working capital, repairs, etc. The maximum make in one of the Lecco fineries was 60,000 kil., or about 60 tons per annum. According to Tunner the iron made by this process is of superior quality, but more soft than hard.

The cinder produced in the first stage of the process at Lecco was composed as follows:—

Silica	28·2
Protoxide of iron	38·1
Protoxide of manganese	25·7
Lime	6·0
Magnesia	2·0
	100·0

The presence of so large a quantity of lime and magnesia Audibert attributes to the blast-furnace slag, with which the cavernous pig-iron is always impregnated. The large proportion of protoxide of manganese should be noted, as showing the rapid elimination of this metal owing to its greater oxidizability than iron.

It is obvious that in this process the oxygen contained in the hammer-slag, etc., plays a chief part in the decarburization of the pig-iron. The intermingling of the refined metal, produced in the first stage, with ferriferous matter rich in oxygen, must tend greatly to promote the oxidation of the carbon in the second stage. This is precisely what is now actually done in the "boiling process" in the puddling-furnace.

SALZBURG PROCESS (*Salzburger Sinter-Arbeit*).

With respect to this process, Tunner remarks, that owing to the present high price of charcoal, it is only interesting in a scientific and historical point of view. Grey pig-iron is operated on, which is subjected to the same preliminary treatment as in the Lombardy process. There is nothing peculiar in the construction of the hearth. The reheating and fining operations are conducted in the same hearth; the former being completed before the latter begins. For every ball 110 lbs. of stamped pig-iron and from 35 lbs. to 40 lbs. of hammer-slag are required. Much cinder is formed, and must frequently be tapped off. The whole time required to form a ball yielding from 130 lbs. to 150 lbs. of finished iron is about 3½ hours. The consumption of pine-wood charcoal is from 40 to 45 cubic feet for 100 lbs. of bar-iron.

THE BOHEMIAN PROCESS (*Böhmische Anlaufschmiede*).[3]

This process, which is classed by Tunner in the same division as the Franche-Comté process, was conducted at Horzawitz, in Bohemia, fifty years ago, in the same manner as at present, and from thence was introduced into Styria.

More or less mottled and even grey pig-iron may be worked in this hearth.

The hearth is formed of four cast-iron plates. The dimensions are: Depth under the twyer, from 10 in. to 11 in.; from the edge of the back plate, 12 in. to 13 in.; from the side facing the twyer, 12 in. to 14 in.; from the fore, or work-plate, 14 in. There is a wall at the back of the back-plate, extending 8 in. above that plate. The mouth of the twyer is semicircular, or quadrangular, 1½ in. broad, 10 to 12 lines high, overlying the twyer plate 3½ in. The blast-pipe lies from 3½ in. to 4 in. back in the twyer; it is circular, and from 10 to 12 lines in diameter; the twyer inclines 10°. The fore-hearth is very long. The hearth is enclosed in front by brickwork having a large opening at the bottom, so that on this side there is no cast-iron plate.

The pig-iron is preferred in pieces 6 in. broad, 18 long, and 1 thick

[3] Tunner, 2. p. 188. The illustrative woodcuts are copied from those of Tunner.

(Austrian measure). Pine-wood charcoal is the fuel used (Kiefer-kohlen).

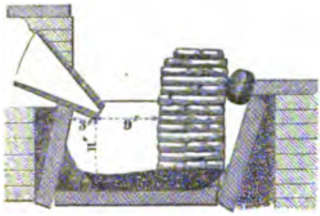

Fig. 122. Section showing the pile of pig-iron.

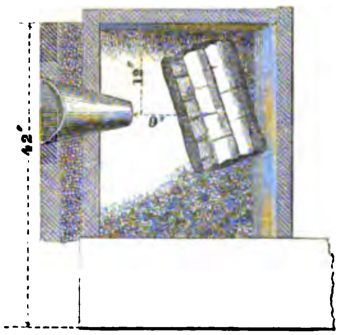

Fig. 123. Plan showing pile of pig-iron.

Small charcoal (Lösch) is put upon the bottom, and especially in the angles. Upon this bed of charcoal is formed another of rich slag, containing from 70 % to 80 % of protoxide of iron, which is made thickest at the side facing the twyer, fig. 122 and fig. 123. Upon the slag bed the pig-iron to be melted is arranged in layers, so as to form a regular pile of from 250 lbs. to 260 lbs. in weight, including from 10 lbs. to 20 lbs. of various small pieces of pig-iron left in the hearth from previous workings, which lie at the bottom next the slag. In the empty space between the side facing the twyer and the pile, only a few pieces of slag are inserted, in order to support the pile. The space between the pile and the twyer side is now filled with charcoal up to the twyer, and the blast put on at a pressure equal to a column of water of from 6 to 10 inches.

The heat of the furnace is, as usual, economized in the reheating of blooms of a previous charge; and during this period (Ausheitzen) the pile must frequently be raised up and brought nearer the twyer. The metal soon begins to melt at the lowest part of the pile, where the blast directly plays upon it. As the pile sinks down, the pieces of slag become useless as supports, and may then be removed. In from half an hour to an hour after the *reheating* process the melting of the pig-iron is completed. For some time previously the pressure of the blast is diminished when the pile is only 3 in. or 4 in. from the twyer. The whole time from the beginning to the end of the melting amounts to 3¼ hours, during which 16 cubic feet of charcoal are consumed. This time will necessarily vary according to the size of the hearth and other obvious circumstances.

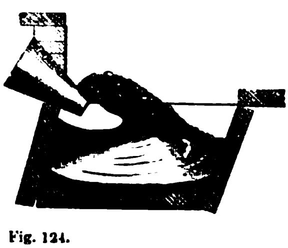

Fig. 124.

After the conclusion of the melting, the pressure of the blast is still further reduced to only 2 in. or 3 in. of water. If much poor cinder be present, it must be tapped off at the uppermost part. But most of the poor slag sweats out during the next step of the process, when the iron "comes to nature." The fuel is now kept up as in the annexed sketch, fig. 124.

The particles of iron near the twyer become semi-solid, partly by

the cooling effect of the blast, and partly by decarburization. The workman scrapes this semi-solid mass away from the twyer, throws in fresh fuel, and places thereon the mass so removed. Provision is now made for tapping off the cinder. To this end, the small charcoal of the fore part of the hearth is scraped out to the depth of 6 in. or 8 in.; and in the hollow so formed, an old slab or similar piece of iron is laid to serve as a support. In doing this, the solid crust next the fore part of the hearth is left undisturbed, in order to prevent the escape of fluid iron and cinder into the hollow. A small bar is pushed under the iron slab so as to pierce the solid crust as high as practicable. Not unfrequently some iron flows along with the cinder; the cinder is thrown away; and if any iron escape, it is placed, after it has become solid, at the top of the charcoal above the twyer. This process of tapping off and raising (Lüften) is many times repeated. The iron slab is in the mean time taken away, in order the better to break up the upper mass which lies against it; it is afterwards replaced somewhat deeper. The above-mentioned manipulation of the mass before the twyer by breaking up the half-fined particles, and imbedding the loose, broken-up pieces in the fuel, proceeds *pari passu* with the sweating out of the poor cinder. By this means the mass above the twyer increases in bulk, as seen in the annexed sketch, fig. 125.

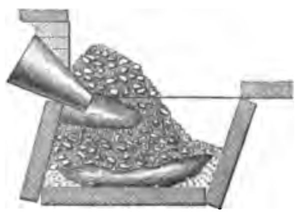
Fig. 125.

The mass of iron at the bottom, especially under the twyer, is several times raised with a bar in order to prevent its setting fast, and the better to prepare it for the "breaking up."

In the course of half, or three-quarters of an hour, the sweating out of the cinder ceases, after which the iron slab support is removed, and its place filled with small charcoal. The mass heaped up above the twyer comes to a gentle "boil" (Kochen), by which its "coming to nature" is much promoted. All is now broken up from the bottom under the twyer; but only raised up (nur gelüftet) on the side facing the twyer, where the iron is still in the state of, only nearly quite fluid, unchanged pig-iron. The staff on which the iron is to be collected is now held in the fire. This part of the process—that of "coming to nature"—lasts 1½ hour: three cubic feet of charcoal are consumed.

The staff, from which the last bloom has been cut off, is hammered smooth at the cut end, and then placed under the twyer. The particles of iron which have thoroughly "come to nature," being at a welding heat, adhere together, and stick to the end of the staff, which is turned round at intervals in order to obtain a regular mass, or ball. (See fig. 126.) The best iron is thus produced. The ball on the end of the staff is worked under the hammer and cut off, the remaining portion of the staff being used to collect the next ball, which is welded to the end of a staff, and wrought under the hammer. Most of the iron melts

down without adhering to the staff, and part of that which has attached itself to the end of the staff is melted off again, so that immediately under the twyer is collected a mass of iron which has thoroughly "come to nature." By thus successively breaking up the metal *under* the twyer, and again piling it up *above* the twyer, the conversion of pig into malleable iron is at length completed. About 2¾ hours are occupied in collecting the metal on the staff, etc., during which 11 cubic feet of charcoal are consumed.

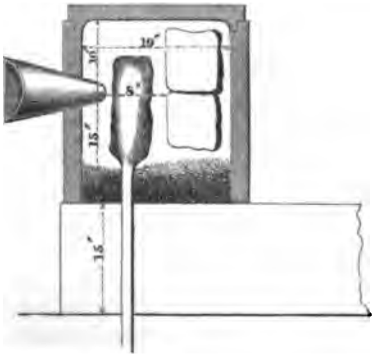

Fig. 126.

The pieces of metal remaining in the hearth, which differ much in respect to degree of decarburization, are collected together and again melted down before the blast, rich slag having been previously added if necessary: a last ball is thus obtained, and subjected to the usual manipulation. This requires 1 hour, during which 3 cubic feet of charcoal are consumed.

The loss of iron burnt away varies from 23 % to 25 %, so that the yield of bar-iron per charge somewhat exceeds 200 lbs. The weekly production of fine bar-iron in one hearth, at Horzawitz, amounts to 35 ctrs., for which 6 or 7 men are employed.

At Reutenhau, near Wiesenberg, in Moravia, the pile of cast-iron is in two parts, as shown in fig. 126, and the hearth is so narrow that the distance between the twyer side and the inner side of the pile is only 8 in.

ROHNITZ PROCESS (*Rohnitzer Arbeit*).[4]

It derives its name from Rohnitz, in Hungary, where it is practised. It most resembles the Bohemian process. The reheating and fining operations take place simultaneously in the same hearth. Mottled or even grey pig-iron is used in charges of 6 ctrs. at a time. The metal, when melted down, is treated as in the Lombardy process, and the manipulation, therefore, need not be described. The hearth is provided with a twyer on each side, inclined from 18° to 20°, so that it is virtually two hearths united, and may be reduced to a single small hearth by stopping the blast from either twyer. The bottom plate is 42 in. long, 4 in. broad, and 3 in. thick.[5] The depth below the centre of the twyers is from 10 in. to 12 in. The twyer plates and back incline a little inwards. The distance between the centres of the twyers and back-plate is 12 in. The metal is completely melted down in about 1½ hour, when the cinder is tapped off. The lump is divided into two or more balls, which are reheated, etc., in the following heat. A charge is worked off in 6 or 6½ hours by five men. The loss on the

[4] Tunner, op. cit. 2. p. 212.

[5] Austrian measures, which, for the reason before assigned, I have not considered it necessary to convert into English.

pig-iron is about 14%. The consumption of pine-wood charcoal is from 25 to 28 cubic feet for 100 lbs. of finished iron.

Descriptions of other processes, such as the Sulu process, the Osemund process, the Half-Walloon process, etc., will be found in various treatises; but there is nothing so peculiar in any of them as to require separate notices.

Slags or Cinders produced in Finery Processes.

The slags produced in several of these processes have been analysed, and the analyses collected and tabulated in a convenient form for reference.[6] German writers divide them into two classes, raw or poor slags (Rohschlacken), and rich slags (Gaarschlacken); the adjectives poor and rich indicating the relative proportions of oxide of iron which they contain.

Poor slags.—These slags are formed in the first operation of melting down the pig-iron, and approximate generally to the formula of iron chrysolite, or olivine, viz., $3FeO,SiO^3$, in which the protoxide of iron may be to a certain extent replaced by protoxide of manganese, lime, and magnesia, the lime and magnesia usually not exceeding 2% each. When pig-iron containing phosphorus is operated upon, these slags may be expected to contain phosphoric acid in sensible proportion; and there is reason to believe that this acid must have existed in many of the published analyses, in which it is not mentioned. It is very desirable that fresh and very careful analyses of some of these slags should be made by competent analysts.

In fifteen analyses tabulated by Lindauer, and presenting nothing exceptional in composition, the mean per centage of silica is 30, and that of protoxide of iron 60.[7] The oxygen of the former is 15·6, and that of the latter 13·3. But most of the slags taken contained protoxide of manganese (the extremes being 6·7% and 0%), lime (the extremes being 3% and 0%), magnesia (the extremes being 2·4% and 0%), and alumina (the extremes being 7·4% and 0%). Sesquioxide is mentioned in only two of the series, and the proportions were 2·25% and 1·04%. Potash appears in two, in the proportions of 0·29% and 0·21%; and phosphoric acid also in two, in the proportions of 16·5% and 5·22%.

According to Lindauer, a slag obtained in fining pig-iron rich in silicon had the formula $2(FeO, SiO^3)+2FeO, SiO^3$; and he arrives at the conclusion that the composition of all finery slags may be represented by formulæ comprised between those of $3FeO,SiO^3$ and $3FeO, SiO^3+3(2FeO, SiO^3)$, the silica between the brackets in the last formula being, as he supposes, partially replaced by sesquioxide of iron. He further concludes that the slag produced at the beginning of the melting-down stage has the formula $3FeO, SiO^3$, while that produced towards the end of it has formulæ ranging from

$$3FeO, SiO^3 + 3(2FeO, SiO^3) \text{ to}$$

$$3FeO, \overbrace{SiO^3, Fe^2O^3} + 3(2FeO, \overbrace{SiO^3, Fe^2O^3}).$$

[6] Vid. Kerl's Handbuch. 2° ed. 1861, 1. p. 868 *et seq.* Lindauer's Compendium, 1861, p. 284 *et seq.*

[7] Op. cit. p. 285. The analyses from which I have deduced the mean are 1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 15, 16, 17, 18.

There can be no doubt that definite formulæ have often been assigned to mere mixtures of definite compounds: and in reference to this subject, attention should be particularly directed to the results of the experiments on the silicates of protoxide of iron previously inserted. I do not know on what ground Lindauer replaces silica by sesquioxide of iron: and the results just alluded to render it probable that no such combinations of sesquioxide of iron exist, and that when that oxide is present, it is in the state of magnetic oxide mechanically mixed.

Rich slags.—They consist essentially of silica and protoxide of iron, with small proportions generally of protoxide of manganese, lime, magnesia, and alumina, and occasionally also of sesquioxide of iron, potash, soda, and phosphoric acid.

In twenty analyses of these slags tabulated by Lindauer, the mean per centage of protoxide of iron is 73·7,[a] the extremes being 85·5 % and 54 %. The extremes of silica are 21·4 % and 5·6 %,—of protoxide of manganese, 11·43 % and 0 %,—of lime, 7·36 % and 0 %,—of magnesia, 3·5 % and 0 %,—of alumina, 3·5 % and 0 %,—of sesquioxide of iron (present only in seven of the series), 16·18 % and 0 %,—of potash (in the five instances in which its presence is recorded), 3·70 % and 0 %,—of soda (in the three instances in which it was stated to be present), 0·57 % and 0·43 %,—of phosphoric acid (in the seven instances in which it was stated to be present), 4·70 % and 0·11 %.

According to Lindauer, the mean composition of these slags may be represented by the formulæ—

$$6FeO, SiO^3 \text{ and } 3(2FeO, SiO^3) + 8(6FeO, SiO^3) + 2(FeO, Fe^2O^3).$$

Now, it has been previously shown that there is strong evidence for concluding that no such formula as 6FeO, SiO^3 exists; and that every attempt to produce a silicate of protoxide of iron with less than 1 equivalent of silica to 1 of protoxide of iron utterly failed. The conclusion at which I have arrived from that evidence, is, that these slags are merely mixtures of tribasic silicate of protoxide of iron (3FeO, SiO^3), protoxide of iron, and magnetic oxide of iron; and until something like proof to the contrary is adduced, I shall not attempt to deduce elaborate formulæ on purely imaginary grounds.

After what has now been advanced in various parts of this volume, I apprehend that the mode in which decarburization of the pig-iron in the finery processes is effected will be sufficiently intelligible to render further discussion of the subject superfluous.

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[a] Op. cit. p. 288.

RUNNING-OUT FIRE, OR REFINERY.[9]

It is represented in Figs. 127, 128, 129. The engravings are from drawings of a refinery at the Bromford Iron-works, near Birmingham, belonging to my friend, Mr. W. H. Dawes. I am indebted to Mr. Arkinstall, the manager, for his assistance in supervising the execution of the drawings. The same parts in the different engravings are as usual indicated by the same letters.

The refinery consists essentially of a rectangular hearth, with three water-twyers on each side inclining downwards. The sides and back are formed of hollow iron-castings, called "water-blocks," through which water is kept flowing, the front of a solid cast-iron plate containing a tap-hole, and the bottom of sand resting on a solid platform of brickwork. Coke is the fuel used with cold-blast at a pressure of 3 lbs. per square inch.

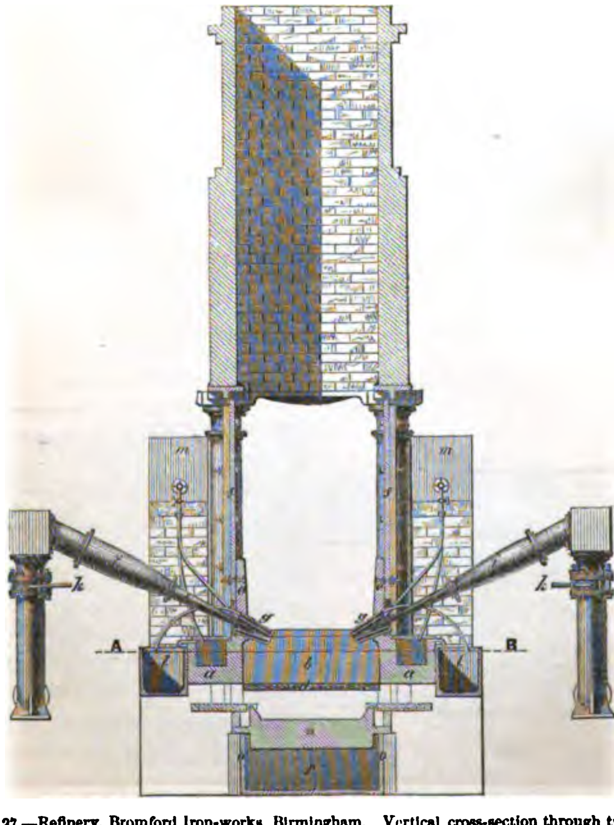

Fig. 127.—Refinery, Bromford Iron-works, Birmingham. Vertical cross-section through two opposite twyers on the line E, F, G, H, I, fig. 128.

[9] The process is termed *mazéage* by the French. Not long ago a gentleman of great experience in the smelting and manufacture of iron recommended the process of mazéage as worthy of adoption in England, not being aware that it was identical with our process of refining.

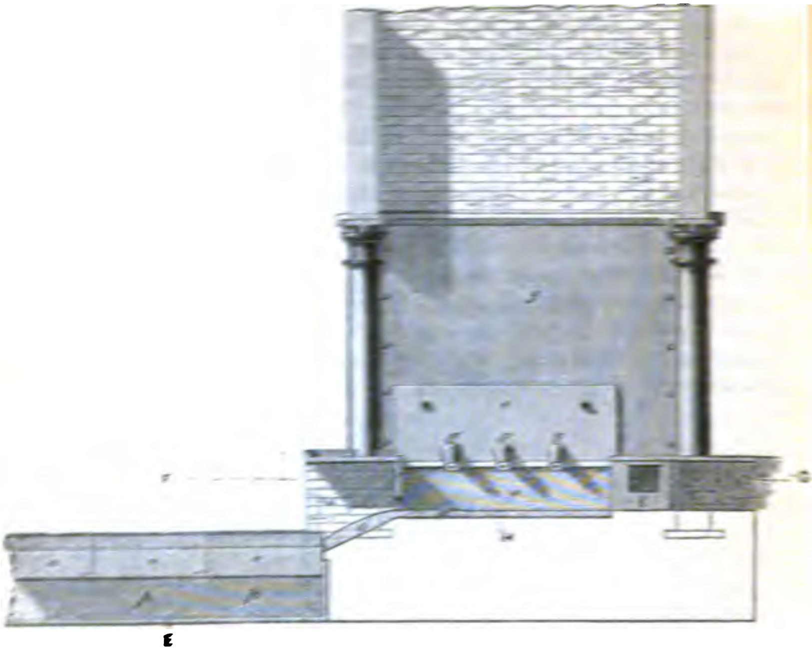

Fig. 128.—Refinery, Bromford Iron-works, Birmingham. Vertical section on the line C D, fig. 129.

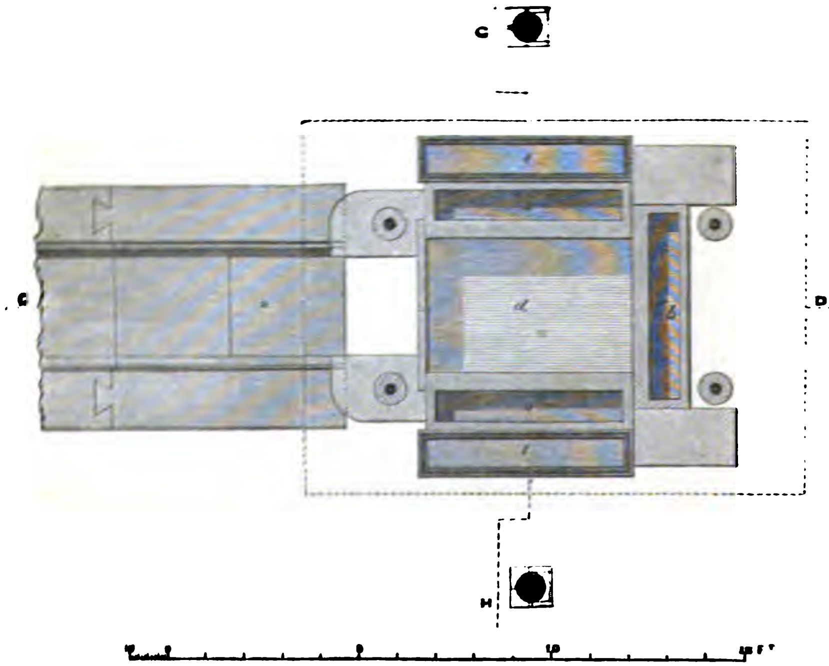

Fig. 129.—Refinery, Bromford Iron-works, Birmingham. Horizontal section on the line A B, fig. 127

Figs. 127, 128, 129, *a*, *a*. Hollow sides of cast-iron.

Figs. 127, 128, 129, *b*. Hollow back of cast-iron.

Fig. 128, *c*. Front, or dam plate of cast-iron, containing the tap-hole. It is also shown in Fig. 129. It is protected within by coke-dust piled up against it.

Figs. 127, 128, 129, *d*. Flat bottom of sand, which is continued beyond the tap-hole plate, from which it slopes downwards.

Figs. 127, 128, *e*, *e*. Plate of cast-iron screwed on *f*, through which the twyers pass.

Figs. 127, 128, *f*, *f*. Cast-iron plate.

Figs. 127, 128, *g*, *g*, *g*. Water-twyers. Their axes, when prolonged, should impinge on the bottom, on the line dividing it into two equal parts.

Fig. 127, *h*, *h*. Blast-pipes.

Fig. 127, *i*, *i*. Leather connecting-pipes between the blast-pipes and the blast-main.

Fig. 127, *k*, *k*. Throttle-valves for regulating the blast.

Figs. 127, 129, *l*, *l*. Water-troughs of cast-iron to receive the water from the twyers.

Fig. 127, *m*, *m*. Tanks of cast-iron for water to supply the sides and back of the hearth, and the twyers with water.

Figs. 127, 128, 129, *n*, *n*, *n*. Long cast-iron, or running-out-bed, to receive the molten metal from the hearth. It is formed of a succession of plates, joined as shown in Figs. 128, 129. The joints are luted carefully with fire-clay to prevent escape of the molten metal, and consequent explosion.

Fig. 127, *o*, *o*. Cast-iron box, forming a channel, *p*, over which the running-out-bed is supported.

Figs. 127, 128, *p*. Channel under the running-out-bed, through which water is kept in circulation for the purpose of refrigeration.

The space immediately over the hearth is enclosed on each side by cast-iron plates, the back with folding wrought-iron doors, and the front with a wrought-iron door suspended at the end of a lever, whereby it may be raised or lowered. Above is a short chimney supported on cast-iron columns, as represented in Figs. 127, 128, 129. Other details of construction will be clearly intelligible without further description.

The refinery being in operation, the folding-doors at the back are opened and coke is thrown in, the charge of about 1 ton or 1 ton 2 cwts. of pig-iron is placed upon it and heaped over with coke, after which the blast is let on. The operation is facilitated by the addition of 30 lbs. of hammer-slag or scale. The metal, which melts in about 1½ hour, is then exposed to the action of the blast, which is strongly oxidizing, notwithstanding the superincumbent layer of incandescent coke. A considerable quantity of cinder is formed, consisting for the most part of tribasic silicate of protoxide of iron. In about 2 hours after charging tapping occurs, the blowing usually lasting about ½ hour. The consumption of coke is about 4 cwts. Cinder and the molten metal flow out together along the running-out-bed in front, the

cinder, of course, forming the uppermost stratum. This bed being refrigerated, as previously stated, the metal speedily consolidates. Water is afterwards thrown over the whole, while the accompanying cinder is still liquid, when the latter puffs up into beautiful little volcano-like craters; and it is curious to watch the molten cinder and water dancing as it were together. After a few minutes the top of the dam at the farthest end of the bed is broken, and the greater part of the cinder runs off and other cinder is removed.

The water, which may be conveniently applied in a strong jet, promotes the separation of the cinder from the metal. The cinder is thrown aside to be either smelted or used for certain other purposes; and the metal, usually about 3 in. in thickness, is removed and broken up in pieces of the proper size for puddling. This metal is white cast-iron, and is termed "refined iron," or "refined metal," "fine metal," "finer's metal," "plate metal," or simply "metal." I have found its upper surface sometimes covered with firmly adherent, small, yet very distinct crystals of iron-chrysolite or tribasic silicate of protoxide of iron. Good metal should be compact and bright on fracture, presenting an almost silvery lustre. It is generally more or less cellular, or, as it is termed, "honey-combed," towards the upper surface; and the longer the blowing the greater the depth of the "honey-combing." If it exceeds 1 in. in depth in 3 in. thickness of plate, the metal is difficult to melt in the puddling furnace.

It is usual to place little ridges of cinder at intervals across the running-out-bed, so that the metal, in flowing over them, may, after solidification, retain on its lower surface a series of corresponding furrows, or lines of weakness, along which it may afterwards be easily broken.

A convenient apparatus is employed for raising and removing the plates of metal from the running-out-bed. It has two wheels, and is much like that used for setting the pots in the English zinc furnace, and which is figured in the First Part of this work. Instead of the clipping part for these pots, a chain is suspended with a clip at each end. The clips are got under the metal by raising it with a crowbar; and when this is done, the long handle of the apparatus is depressed, and the metal lifted up. But as it cannot be conveniently balanced on a single chain, the end towards the long handle is caught by another clip, and so the whole is wheeled away.

At the Cyfartha Iron-works of Messrs. Crawshay, in 1859, I observed refineries of two kinds: one with two twyers at the back and none at the sides, and the other with two twyers on each side and none at the back. At the Blaina Iron-works, the twyers were more inclined than I have seen elsewhere in South Wales. It was in these refineries that I remarked the formation and projection of minute spherical shots; but I saw none at those of Cyfartha. The inclination should be greater in the case of grey pig-iron.

In the refineries of the Ebbw Vale Iron-works, in 1859, a charge consisted of about 33 cwts. of pig-iron, and the yield was 30 cwts. of refined metal.

At Pentwrch, according to Mr. Thomas, of Merthyr, the charge in the coke refinery was 9 cwts. of good mottled pig-iron, and the yield of refined metal about 8 cwts.

Severe explosions have not unfrequently occurred in the operation of refining. They have been generally produced by the running of the molten metal through the bottom of the running-out bed into the water underneath. Mr. Parry informs me that he was standing near a refinery at the Ebbw Vale Iron-works, when an explosion from this cause took place, with a report as loud as that of artillery. The roof of the building was blown off. Mr. Menelaus has apprised me that within the last few years two men have been killed by similar explosions at the Dowlais Iron-works. The mode of joining the bottom plates shown in fig. 130 has been adopted successfully, with a view to prevent explosion from the cause in question.

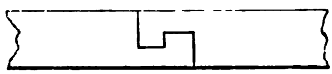

Fig. 130. Section, showing mode of joining bottom plates.

I have not yet been able clearly to ascertain the history of the refining process, which, probably, was gradually arrived at. In 1771 a patent was granted to John Cockshutt, for "making malleable iron directly from the ore in a finery or bloomery," and "refining pig-iron with charcoal into wrought-iron," and "a new finery or bloomery."[1] The finery is described as made of metal plates, open on two or more sides, so that men might work at least on two sides. Instead of only one twyer, there were several, "so as to direct the wind from the bellows to operate upon the iron in every part of the fire." The number of twyers was to be regulated according to the nature of the iron. There is, obviously, a considerable resemblance in construction between the "new finery" here described and the modern refinery.

The merit of the invention of this process is ascribed by the late Mr. S. B. Rogers, formerly of the Nant-y-glo Iron-works, to Mr. Homfray, of Tredegar.[2] Mr. Rogers states, "It was long before I went to Pontypool (1808), because it was generally adopted at that time. This invention was a modification of the old charcoal *running-out* fires, in which the pigs were (a few at a time) melted, run out, and when set, thrown up on the fire again and remelted, two, three, and occasionally four times over, according to the quality of the pig-iron. This was, I think, done at Beaufort with coke, in Mr. Latham's time." (About 1810.)

Mr. Parry remarks that the present system of refining by one melting, and then blowing upon the molten metal for a certain time, according to the degree of decarburization needed, is a subsequent invention by some person unknown. The late Sir John Guest, of Dowlais, appears to have been the first to save the remelting of the pig-iron by running the metal direct from the blast-furnace into the refinery.

The first refineries were built of fire-brick, but, owing to the great

[1] Abridgments of the Specifications relating to the Manufacture of Iron and Steel, p. 8, A.D. 1771, May 2.—No. 988.

[2] Communicated by Mr. Rogers to Mr. Parry, and by the latter to the author. He died recently, above 80 years of age.

wear and tear, brick was gradually superseded by the "water-block," first at the sides, and then at the back, but never in front.

At the Ebbw Vale Iron-works 30 or 40 years anterior to 1859, salted coke,—prepared by steeping in brine, draining, and drying,—was used in the refinery for making *best* cable-iron.

Composition of Refined Iron.

A characteristic specimen of metal which I saw refined in 1856, at the Bromford Iron-works, in the refinery of which a description has been given, was analysed in my laboratory by Mr. A. Dick, and found to be composed as follows :—

Carbon		3·07
Silicon		0·63
Sulphur		0·16
Phosphorus		0·73
Manganese		trace
Residue insoluble in hydrochloric acid	Silica	0·30
	Alumina with a little sesqui-oxide of iron	0·14
Iron		95·14
		100·17

Its upper surface was covered with small, distinct, and firmly adherent crystals, in the form of iron chrysolite or olivine. The pig-iron operated on was grey; but, unfortunately, no analysis of it was made, and I failed to procure any information concerning it. The silica and alumina were, doubtless, accidentally present. The proportion of carbon is much larger than I should have expected; but it is possible that the pig-iron may have been rich in silicon, and that this element may have been chiefly separated in the process in combination with protoxide of iron.

The following determinations were made by Mr. Parry of the silicon and sulphur in common white pig-iron and the refined metal obtained therefrom :

	Pig-iron. Per cent.	Refined metal.
Silicon	1·27	0·14
Sulphur	0·93	0·52

The refining was conducted, as usual, under coke.

According to Mr. Parry's observations, grey pig-iron containing 3% of silicon and 0·2% of sulphur will, after having been refined, contain about 0·3% of silicon and 0·15% of sulphur; and white pig-iron, which, before refining, contains about 0·4% of silicon and 2·0% of sulphur, will afterwards contain about 0·1% of silicon and 1% of sulphur.

Composition of Refinery Slags or Cinders.

They are always black or bluish black, vitreous, or semi-metallic in lustre.

I. II. The following analyses were made by Mr. E. Riley at Dowlais. Both were produced at Dowlais from white pig-iron, intended for the manufacture of cable-bolt-iron. The charge of ore in the blast-furnace consisted of 3 parts by weight of Welsh mine (argillaceous

iron-ore), and 1 of red ore (anhydrous hæmatite). No. I. was porous cinder of the ordinary kind, and No. II. was crystallized in plates. Mr. Riley states that he always found this kind of cinder produced in refining siliceous pig-iron (*i. e.* containing from 1½ % to 2 % of silicon), which the refiners term "strong, but difficult." Both of these cinders approximate to the formula $3FeO,SiO^3$. III. This cinder was produced at the Bromford Iron-works, and was analysed (1845) in my laboratory by Mr. David Forbes. It was crystallized in the form of iron chrysolite or olivine. It is clearly to be regarded as tribasic silicate of protoxide of iron, containing a considerable amount of foreign matter, represented especially by the alumina, which no doubt was chiefly derived from the ashes of the coke.

		I.	II.	III.
Silica		25·77	33·33	22·76
Protoxide of iron		65·52	54·94	61·28
Protoxide of manganese		1·57	2·71	3·58
Alumina		3·60	5·75	7·30
Lime		0·45	1·19	3·41
Magnesia		1·28	0·50	0·76
Sulphur		0·23	..	0·46
Sulphide of iron (FeS)	Iron	..	0·17	..
	Sulphur	..	0·10	..
Phosphorus		1·37	0·99	not determined
Copper		..	traces	..
		99·79	99·68	99·55

PUDDLING.

This process, as has been previously remarked, consists essentially in stirring about pig-iron molten on the bed of a reverberatory furnace, heated by flame, until it becomes converted into malleable iron, through the decarburizing action of the oxygen of the air circulating through such a furnace. Thus all contact between the metal and solid fuel is avoided, and the necessity of blowing machinery is dispensed with. This invention is usually ascribed to Henry Cort, by whom it was patented in 1784.[3] The specification occupies about two pages, and is as follows:—

"For the preparing, manufacturing, and working of iron from the ore, as well as from sow and pig metal, and also from every other sort of cast iron (together with or without scull and cinder iron and wrought-iron straps), I make use of a reverberatory or air furnace or furnaces of dimensions suited to the quantity of work required to be done, the bottoms of which are laid hollow or dished out, so as to contain the metal when in a fluid state. My furnace for the first part of the process being got up to a proper degree of heat by raw pit coals, or other fuel, the fluid metal is conveyed into the air furnace by means of ladles or otherwise. When this air furnace is charged with sow and pig metal, or any other sort of cast-iron, the door or doors of the furnace should be closed till the metal is sufficiently fused, and when the workman discovers (through a hole which he opens occasionally) that the heat of the furnace had made a sufficient impression

[3] Manufacture of Iron, A.D. 1784. No. 1420.

upon the metal be opened a small aperture or apertures, which I find it convenient to have provided in the bottom of the doors, but which is or are closely shut, as well as the doors, at the first charge of the furnace with such cast metal; and then the whole is worked and moved about through those apertures by means of iron bars and other instruments fitly shaped, and that operation is continued in such manner as may be requisite during the remainder of the process. After the metal has been some time in a dissolved state, an ebullition, effervescence, or such like intestine motion takes place, during the continuance of which a blueish flame or vapour is emitted; and during the remainder of the process the operation is continued (as occasion may require) of raking, separating, stirring, and spreading the whole about in the furnace till it loses its fusibility, and is flourished or brought into nature; to produce which effect, the operations subsequent to the fused state are the same, whether the fusion be made in the air furnace, or the metal be conveyed into it in a fused state, as first mentioned. As soon as the iron is sufficiently in nature, it is to be collected together in lumps, called loops, of sizes suited to the intended uses, and so drawn out of the door or doors of the furnace, when all the small pieces that may happen to remain are also cleared away. It has been found by me to be a good method of using such small pieces last mentioned, and also scull or tinder iron, first broken into small pieces; and also all sorts of parings of iron plate, or other thin iron, and nut or bushel iron, commonly called wrought straps, to throw them into the furnace in various proportions during the operation of bringing the fused metal into nature, and before it is collected into loops, and as the whole charge of the furnace is raked and stirred about, these straps become lapped up in the loops after the fused metal is flourished and got into nature. And the whole of the above part of my method and process of preparing, manufacturing, and working of iron is substituted, instead of the use of that finery, and is my Invention, and was never before used or put in practice by any other person or persons. The iron so prepared and made may be afterwards stamped into plates, and piled or broke and worked in an air furnace, either by means of pots, or by piling such peices in any of the methods ever used in the manufactory of iron from coke fineries without pots; but the method and process invented and brought to perfection by me, is to continue the loops in the same furnace, or to put them into another air furnace or furnaces, and to heat them to a white or welding heat, and then to shingle them under a forge-hammer, or by other machinery, into half blooms, slabs, or other forms, and these may be heated in the chaffery according to the old practice; but my new Invention is to put them again into the same or another air furnace or other furnaces, from whom I take the half blooms, and draw them under the forge-hammer, or otherwise, as last aforesaid, into anthonies, barrs, half flatts, small squared tilted rods for wire, or such uses as may be required; and the slabs having been shingled in the foregoing part of the process to the sizes of the grooves in my rollers, through which they are intended to be passed, are worked by me through the grooved

rollers, in the manner which I use bar or wrought-iron fagotted and heated to a welding heat for that purpose. Which manner of working any sort of iron in a white or welding heat through grooved rollers, is entirely my own Invention. Iron and also steel so prepared, made, wrought, and manufactured, by such effectual application of fire and machinery, will be discharged of the impurities and foreign matter which adheres to them when manufactured in the methods commonly practiced. The steel is of an excellent quality, and the iron will be found to be good tough iron in barrs and uses, whether large or small, and in all sorts of merchant iron, whether it be made from mettal of a red short or cold short nature; and blistered steel, whether made from iron prepared according to the above process, or from any other iron when faggoted together, heated to a white or welding heat, rolled in that heat through grooved rollers, according to the method invented by me, and slit through the common cutters, is equal to steel manufactured by forge and tilt hammers. The whole of which discovery and attainment are produced by a more effectual application of fire and machinery, as described by me, than was before known of or used by others, and are entirely new and contrary to all received opinions amongst persons conversant in the manufactory of iron; and the whole of my method may be compleated without the necessity of using finery, charcoal, cokes, chaffery, or hollow fire, and without requireing any blast by bellows or cillinders, or otherwise, or the use of fluxes in any part of the process. The whole operation to be performed with one or more furnaces, according to the quantities or dispatch required."

In 1783, the year preceding, Cort obtained a patent for the so-called grooved rolls, now known as "puddle rolls," by which the bloom resulting from a preliminary forging of the ball might be drawn out into bars, instead of being extended, as heretofore, under the hammer.[4]

The story of Cort's invention is a sad one, and has excited much commiseration. He died in poverty, though he laid the foundation of the riches of many an ironmaster, and has largely contributed to the development of the resources and wealth of Great Britain. The transactions which led to his ruin may be told in few words.[5] Cort

[4] Preparing, Welding, and Working Iron, A.D. 1783. No. 1351.

[5] The son of Cort, Mr. Richard Cort who still survives, and is now at an advanced age, has collected and published the materials, which contain all needful information concerning these transactions. A compendious account will be found in the "Statement of the Claims of the Surviving Members of the Family of the late Henry Cort for National Compensation," put forth a few years ago by a committee formed with a view of submitting those claims to Parliament and to the attention of the public at large. It is signed by James Booth, LL.D., F.R.S., Chairman of the Cort Committee. I have chiefly derived my information on the subject from this report; but I have also perused various other documents communicated to me by Cort's son. It is to be regretted that some of the advocates of Cort, in excess of zeal, should have acted injudiciously and exposed themselves to the charge of exaggeration. One gentleman some time ago warmly espoused Mr. Richard Cort's claims, and published several letters in the papers on the subject. He advocated a parliamentary grant of several thousand pounds; but he was not so disinterested as might have been supposed. I have seen a letter from him citing an agreement to the effect that, in the event of the grant being obtained, he should receive a very large share of it. I have a copy of this letter in my possession, the correctness of which is duly attested.

entered into large contracts to supply rolled iron to the Navy, and expended the whole of his private fortune—exceeding, it is reported, 20,000*l.*—in bringing his process to a successful issue. He was, accordingly, obliged to seek additional capital, and with that object he entered into an agreement with Mr. Adam Jellicoe, Deputy Paymaster of the Navy, the conditions being that the latter should advance 27,000*l.* on the security of an assignment of the patent-rights, that he should receive half the profits which might accrue from the manufacture, and that his son, Mr. Samuel Jellicoe, a clerk in the Navy Pay Office, should, as his father's representative, enter into partnership with Cort. This partnership was perfectly known to, and sanctioned by, the heads of the Navy Board, as may be inferred from the fact that the Board not only entered into large contracts with the firm of Cort and Jellicoe, but publicly advertised (April 16th, 1789) that "no tenders for this iron will be regarded, but from persons who prove that they make it agreeable (*sic*) to Messrs. Cort and Jellicoe's patent." Such an announcement from a Government department may now-a-days excite surprise and disgust: but it was in entire accord with the corruption which then prevailed in the administration of the public service. Let us hope that in the present day, at least, we are secure against indirect bribing of official underlings. The heads of boards must necessarily in a great degree rely upon the reports of their subordinates as to the quality of metals or other articles which may be supplied; and it is easy to conceive that the framers of such reports may be unconsciously influenced by the civilities of one kind or other which they may receive from contractors.

Mr. Jellicoe, senior, died suddenly in 1789, when it was discovered that the capital which he had advanced to Cort had been withdrawn from the cash balances lying in his hands, and that he was indebted to the Government to a still larger amount. Two Government "extents" were forthwith issued from the Navy Board: one against the property, works, and trade effects of the firm of Cort and Jellicoe, at Fontley and Gosport; and the other against the private estate of Mr. Jellicoe, deceased, including among his effects the patent-rights of Cort. According to the valuation of the sheriff's jury, the former alone were worth nearly 17,000*l.*, and it is alleged that the sale of the property, even at a loss, would have so far reduced the debt that the remainder would have been speedily liquidated by the temporary sequestration of the patent-rights.[a]

But this, the obviously just course, was not adopted. Instead of disposing of the Hampshire works, and applying the proceeds to the liquidation of the debt due by the firm, Mr. Samuel Jellicoe was put in possession of this property, whilst the patent-rights of Cort were treated as valueless—being only estimated at 100*l.*—and were absolutely confiscated. Yet it is asserted to have been subsequently proved that the collection of the royalties from licensees under the patent

[a] I have here, as well as subsequently, in great measure, employed the *ipsissima verba* of the "Statement," to which I have alluded as the chief source of my information.

would have paid the deceased Mr. Jellicoe's debt, principal, and interest at least six times over. It is further maintained that, by this arbitrary procedure, property to the amount of 250,000*l.* was either absolutely annihilated, or disposed of in a manner to which there is now no clue. The result was the complete and irretrievable ruin of poor Cort.

On the 17th of May, 1790, Cort urged on the notice of the Paymaster of the Navy, Mr. Alexander Trotter, the fact of the increasing make of puddled and rolled iron, and "offered his personal services to procure such necessary information as to render the patents productive." (There were two: one, to be hereafter described, for the use of grooved rolls in drawing out the puddled balls into bars, and the other for the process of puddling.) To this offer Mr. Trotter did not condescend to reply. To a subsequent application of the same kind from Mr. Cort to the Commissioners of the Navy, July 14th, 1791, when there was reason to believe that the annual make of puddled and rolled iron had reached 50,000 tons, the following reply was vouchsafed:—"Your invention appears of that utility as to induce them (the Commissioners) to give encouragement to the manufacture of British iron according to the methods that have been practised by you."

Although somewhat irrelevant, yet I cannot forbear to insert the following startling passages from the statement signed by Dr. Booth: "To the treatment of Henry Cort by the Naval Administration, that of the Treasurer of the Navy, Lord Melville, by the heads of the Government, affords a striking contrast. In the year 1800, a few days after Henry Cort's death, when *he* could no longer claim any share of remuneration, and his infant children were incapable of asserting their rights, Lord Melville presented a memorial to the Lords of the Treasury, setting forth *the great merit and uncontested value of Henry Cort's inventions*, and petitioning on that account a release to *himself* of nearly 25,000*l.* (being the amount for which he stated himself to be then responsible on account of Jellicoe's defalcation), towards the discharge of his own defaults as Treasurer (at that time exceeding 190,000*l.*), which grant, as Mr. Pitt admitted on Lord Melville's impeachment, was forthwith made to the petitioner, without hesitation or inquiry, by writ of Privy Seal, dated 27th of May, 1800."

"When in 1803 Parliament had appointed a Commission of Naval Inquiry to examine the irregularities of the Treasurer, Lord Melville, and his Paymaster, Alexander Trotter, they mutually agreed, a few weeks before the sitting of the Commission (by a joint release exhibited on the subsequent impeachment of Lord Melville), to burn, and accordingly did burn, their accounts for 134,000,000*l.* of public money which had passed through their hands. The evidence of Henry Cort's wrongs was destroyed with the rest, and the parties implicated refused, before both Houses of Parliament, to answer any questions tending to criminate themselves."

In 1794 the Lords of the Treasury granted Cort an annual pension of 200*l.*, which by deductions was reduced to about 160*l.* On his death, in 1800, his widow memorialised the Government for assistance,

on the ground that by the death of her husband she was deprived of the only means of support for herself and ten children. Sir Benjamin Hammond, then Comptroller of the Navy, reported thereon as follows, November 20th, 1801:—"That it was a fair recital of facts, and that it was owing to the persevering industry of the patentee that the use of the puddling furnace, and his discovery of grooved rollers for the manufacture of bar-iron, were brought to light; and that in his opinion the said Elizabeth Cort and her family were real objects of national relief:" whereupon she received an annual pension of 125*l.*, reduced by deductions to less than 100*l.*

At a general meeting of ironmasters, held at Gloucester in 1811, the subject of Cort's claims was considered, and a subscription was commenced, which finally amounted to the *large* sum (for wealthy ironmasters, who had so greatly profited by Cort's invention) of 871*l.* 10*s.*

In February, 1812, Cort's eldest surviving son petitioned the House of Commons for an additional reward on the ground of the national importance of his father's inventions. A Committee was appointed, which included three members of an administration consisting of the political successors of that under which Cort had been ruined, viz., Sir Thomas B. Thompson, Comptroller of the Navy, John Wharton, Secretary to the Treasury, and J. W. Croker, Secretary to the Admiralty, besides two admirals; and the then First Lord of the Admiralty was the son of Lord Melville previously referred to. The Committee reported to the effect that Cort was *only one out of several individuals* to whose inventions the vast extension of the British iron trade during the preceding thirty years was attributable, and that his merits had been sufficiently acknowledged by the pensions conferred on himself and his widow, adding, however, a recommendation to the House to grant "such a moderate sum as may cover the expenses necessarily incurred during the investigation." The House came to no decision on the Report of the Committee, and the impoverished family were obliged to pay their expenses, amounting to about 250*l.*, as they best could.

On the death of Mrs. Cort, in 1816, an annual pension of 25*l.*, reduced by deductions to less than 20*l.*, was conferred on each of two surviving unmarried daughters. In 1856 Lord Palmerston assigned out of the Civil List an annual pension of 50*l.* to Cort's only surviving son, whose claims on the bounty of the nation had been represented to his Lordship by the author of this work amongst others.

Now comes the shabbiest part of this melancholy story, which I would gladly have passed over in silence. In 1787 Mr. Richard Crawshay and his partner, Mr. James Cockshutt, visited Cort's works, and there witnessed for the first time the new methods of puddling and rolling.[7] Mr. Crawshay, being convinced of the value of these processes, determined to adopt them at Cyfartha, and agreed to pay Cort ten shillings per ton on all bar-iron which he should thereby

[7] Facts and Proofs collected by R. Cort. London: Printed by Thomas Brettell, Rupert Street, Haymarket, 1855, p. 8.

manufacture. Documentary evidence will presently be cited in proof of this statement. Mr. Richard Crawshay, in a letter to Mr. J. Weale, secretary to Lord Sheffield, dated March 14th, 1808, stated that he took the plans of puddling and rolling iron from "a Mr. Cort, who had a little mill at Fontley." [8]

The only witnesses against the petition to the House of Commons in February, 1812, were Mr. Samuel Homfray, the reputed inventor of the modern coke refinery, and Mr. William Crawshay, who assured the Committee that "his family would have been ruined had they followed Mr. Cort's plans for rolling and puddling." Let the reader mark and remember this declaration.

The evidence of Mr. Homfray before the Committee deserves to be more publicly known and permanently recorded, and here it is: [9]—

Samuel Homfray, Esq., examined.

14th February, 1812.

"The first I ever saw or heard of Mr. Cort was about 25 years ago. 1. Was puddling, or any process very similar to it, in use before Mr. Cort communicated his alleged invention?—Yes, under the name of 'buzzing,' [1] at Colebrook Dale and Yerton. I never heard who invented it. 2. Is there no part of Mr. Cort's invention considered by you as really his?—Not any, except by varying the size and shape of the furnace. 3. To what do you attribute the present improved quality of British iron?—To making finer's metal. 4. Is not finer's metal subsequently submitted to the puddling process?—Yes, exactly the same as Mr. Cort did by the pig. 5. Are the processes called buzzing and puddling essentially the same?—Yes. 6. Was buzzing practised before the date of Mr. Cort's patent in the year 1783?—It must have been about that time. I know nothing of it earlier. 7. What do you know of the use of fluted rollers?—The first I ever knew were used by Mr. Butler, of Rochester [? Rogerstone], near Newport, who claimed the invention of grooved rollers. 8. Was this prior to Mr. Cort's patent in 1784? [2]—Yes, in the year 1782. [*17th February*, 1812.] 9. Is the plan detailed in Mr. Cort's petition followed by any manufactory?—Not one to my knowledge. 10. Is not the process to which finer's metal is subjected the same as that described by Mr. Cort as practised on pig-iron?—No, it is not the same process. 11. Describe the process to which finer's metal is subjected. [*Answer not given.*] 12. You have mentioned some practices by which the quality of iron has been recently deteriorated; you will please to describe them?—By the workmen putting in unrefined pig or scrap iron. 13. Who was the person that introduced the buzzing process?—The first I

[8] Op. cit. p. 12.

[9] Ibid.

[1] I have applied to Mr. Darby for information concerning "buzzing," and his answer is, that he thinks it is what is sometimes called "bustling," the term applied, for example, at Pontypool, to the process of working scrap-iron in the charcoal hearth. (September, 1863.)

[2] The dates of the patents for grooved rolls and puddling are confounded, that of the former being 1783, and that of the latter 1784.

heard of was done by the Colebrook Dale Company and Mr. Wheeler at Verton. 14. Is the puddling furnace heated by raw pit-coal absolutely required to produce iron of the present improved quality from finer's metal?—Yes, it is. 15. What variation was there in the size and shape of the furnace used in the buzzing process from that used by the late Mr. Cort in the puddling process?—Very little difference, except being something smaller. 16. Did you ever see a welding furnace charged with 'blooms' from the coke fineries and rolled into bars fit for merchant service previous to the years 1783 to 1784?—I have seen iron put into a furnace and come out with a welding heat long before I heard of Mr. Cort, and rolled into plates, *but not into bars*." [*Witness withdrew.*]

That the Mr. Butler above alluded to obtained his knowledge of making and using grooved rolls from a Welsh workman who had been employed by Cort at Fontley, is established by a letter of that workman, in which he admitted the fact that on returning to Wales, he had, at the request of Mr. Butler, communicated to him all the particulars.[3]

In an interesting letter of Mr. Cockshutt, partner of Mr. Richard Crawshay, the merit of the inventions, both of grooved rolls and puddling, is freely accorded to Cort. It is excessively damaging to the memory of Homfray, and is so important in its bearing on the question under consideration, that I present it *in extenso*:—

"Wortley Iron-works, April 17, 1812.

"DEAR SIR,—I had heard, I believe, not less than two or three years before I felt it needful to pay any particular attention to the subject, of the great advantages, and the great improvements obtained by your father's practice of rolling iron, in preference to the long continued and established method of forming bars by the use of forge hammers. But when Mr. Crawshay (then my partner) determined that a trial should be made of your father's method of making iron on the puddling system, I accompanied him to Fontley, when I first saw the practice of forming bars from blooms by the use of grooved rolls, and this, by a reference to my remarks made at the time (and now before me), was in the month of June, 1787, with which I was greatly pleased, and that operation was also determined to be made a part of our trial at Cyfartha. Shortly after my return I began to prepare plans and drawings for a more powerful mill for that purpose, with such improvements as occurred to me; and accordingly a mill was constructed on a plan which perhaps has not been much improved since that time, but, I believe, much imitated.

"I have always considered and believed that the merit of rolling bars from blooms was due to your father, as well as that of making iron by the puddling process, both of which Mr. Homfray (who kept an attentive eye over our process) was glad (with my permission) to copy, not only in the construction of his furnaces after the patterns of those erected by your father's workmen, by whom Mr. Homfray was

[3] Op. cit. p. 14.

first instructed when he took up the process, and who also borrowed the very patterns made use of by me in the construction of the mill at Cyfartha. I must add, if Mr. Crawshay had not been convinced himself of your father's just claims, he would not have consented to pay ten shillings per ton for patent right.

(Signed) "JAMES COCKSHUTT."

The letter was addressed to Mr. Coningsby Cort.

In another letter Mr. Cockshutt contradicts the assertion of Mr. Homfray, that without the refinery the process of puddling could not be successfully practised: he states "that it appears to me, without the use of the puddling furnace, the discovery (if it may be deemed a discovery) of making run-out-metal would be of little or no advantage."

Further documentary evidence of a decisive character is also given in the 'Facts and Proofs,' but sufficient has now been introduced to prove that Cort first systematically conducted the processes of puddling and of drawing out the puddled balls through grooved rolls.

With respect to the invention of grooved rolls, it has been maintained that Cort's claim is invalidated by the old patent granted to John Payne in 1728, to which I have previously alluded when treating of the utilization of blast-furnace cinder.[4] The following extract from the specification contains what relates to grooved rolls:—The improvements in the manufacture of iron consist "in putting certain ingredients into fusion with pig or sow iron; videlicet, the ashes of wood and other vegetables, all kinds of glass and sandever, common salt and rock salt, argile, kelp, and pot ash, slegg or cinders from iron furnaces and forges, proportionable parts of the said ingredients being put into fusion or melted with pig, sow, or other brittle iron, which will make the like change as charcoal does in the fire called the finery in common forges, and will render the same into a state of malleability, as to bear the stroke of the hammer, to draw it into barrs or other forms att the pleasure of the workman, and those or other barrs being treated in the said melted ingredients in a long hott arch or cavern, as hereafter is described; and those or other bars are to pass between two large mettall rowlers (which have proper notches or furrows upon their surfass), by the force of my engine hereafter described or other power, into such shapes and forms as shall be required." The engine consisted of a large vane wheel hung in a frame in the side of a building, the pressure of the in-current of air being directed upon the extremities of the vanes.

That something very like grooved rolls is here described cannot be denied; but there is not, so far as I am aware, the slightest evidence to show that Payne ever attempted to carry out his scheme into practice. Indeed the proposal to work the notched rolls by such a wheel

[4] A.D. 1728, November 21. No. 505. It was for "Machinery for obtaining motive power by atmospheric pressure acting upon vanes used for ventilation. Improved furnaces and boilers for applying heat. Improvements in the manufacture of iron and salt." Abridgments, etc., *ante cit.* p. 4.

as is specified, pretty clearly shows that Payne was not aware of the power needed to drive any machinery equivalent to puddle rolls.

With respect to Cort's claim as the inventor of puddling, it has been urged that it cannot be maintained in face of a patent granted in 1766 to Thomas and George Cranage.[5] In their specification this somewhat startling passage occurs:—"The pig-iron is put into a reverberatory or air furnace, built of proper construction, and, without the addition of anything more than common raw pit-coal, is converted into good malleable iron, and being taken redhot from the reverberatory furnace to the forge hammer, is drawn into bars of various shapes and sizes, according to the will of the workman."

This is without doubt the essence of the invention of puddling, viz. the application of heat by means of flame to pig-iron on the bed of a reverberatory furnace. But the question arises, did Messrs. Cranage ever attempt to carry into practice the plan described in their specification? If they did not, they are entitled only to the credit of a notion, and not to that of an invention, properly so called. Thousands of persons may entertain, and even record, their notions concerning supposed improvements in the arts, yet may not proceed one step further. The merit of invention attaches not to such persons, but to the individual who actually *does* that which may have been perhaps only vaguely imagined by others. The Messrs. Cranage were skilful workmen at the Colebrookdale Iron-works; and that they did actually practise the process of puddling with success will appear from the following statement of Mr. Richard Reynolds, son-in-law of Mr. Abraham Darby. Mr. Reynolds at that time managed the works; and, on being applied to by Mr. Cort, with reference to the introduction of his patent at Colebrookdale, he replied, "If thou wilt come with me to the works, I will soon show thee the thing done." They went, and Mr. Reynolds called a skilful workman, named Thomas Cranage. "Tom," he said, "make a ball out of the furnace for this gentleman." Cranage put in some white iron—cold-blast mine iron—and soon brought out a ball of puddled iron. Mr. Adams of Ebbw Vale, to whom I owe the information, says that he has heard this anecdote related more than once by the late Joseph Reynolds, son of Richard Reynolds. Mr. Adams further states, "the belief amongst our old people was that Cort was not the inventor of puddling—at all events, he had not a prior claim to the discovery." This is strong evidence against Cort's claim to priority in the invention of puddling; but, it may reasonably be asked, why was not this invention actively carried out at Colebrookdale—as it does not appear to have been? Either there must have been some difficulty, or its importance was not properly appreciated. One or both of these causes may have operated. Now, Cort unquestionably did succeed, and rightly apprehended the great value of puddling; and, on these grounds, he is, I submit, entitled to merit as great, if not greater than that of his predecessor.

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[5] A.D. 1766, June 17. No. 851. Making pig-iron malleable in a reverberatory or air furnace with raw pit coal only. Abridgments, etc., *ante cit.* p. 8.

But there is another patent, just anterior to Cort's for puddling, which deserves careful consideration. I allude to that granted to Peter Onions, May 7, 1783.[6] It is a highly interesting patent in other respects, and is illustrated with drawings which leave no doubt as to the nature of the invention. I give the following extract from the specification, with copies of the illustrative engravings:—

"There are two furnaces used in this operation or invention, to wit, a common furnace, in which the iron ore or metal is put, and there smelted or melted, and another furnace which is made of stone and brick and other materials, as usual, and fit to resist the force of fire, and bound with iron work and well annealed, and described in the Plan or Drawing thereof hereto annexed, marked with the letter A, and into which the fluid iron or metal is received from the common furnace or smelting blast in its hot liquid state, and when so received is worked or refined as follows:—A quantity or stream of cold water must then run or be put into the cistern or trough under the ash grate of the refining furnace, and the doors thereof closed and luted with sand or lome, and the fireplace filled with fuel of pit coal, coaks, or wood charcoal, from time to time as occasion requires, and then the common bellows, cylinder, or usual machine for blowing or pumping air into the space below the ash grate through the tubes (as described in the Plan) is began to be worked, and the fire excited by the air till the cavity of the said furnace is sufficiently heated, and then the hot liquid iron metal is taken and carried in iron ladles from the above common furnace and poured into the refined furnace through an iron door or apperture raised by a lever (as described in the Plan); then the said apperture is stopped, and the blast of air and the fire used until the metal becomes less fluid and thickens into a kind of paste, which the workman, by opening the door, turns and stirs with a bar or other iron instrument or tool, and then closes the apperture again, and must apply the blast of air and fire untill there is a ferment in the metal; and if no ferment ensues, then he must turn or convey the blast of cold air through the tube (which is described in the Plan) upon the matter, which will excite a kind of ferment or scoriafication in the matter or metal; and as the workman stirs or turns the metal it will discharge or seperate a portion of scoria or cinder from it, and then the particles of iron will adhere and seperate from the scoria, which particles the workmen must collect or gather into a mass or lump, and then shut the door and heat the mass until the same becomes of a white colour, and then take or convey out of the furnace, with a bar of iron or tongs, the said mass or lump to the forge hammer, and there, by repeated blows, squeeze or beat out the remaining scoria or cinder, when a mass of malleable iron will be formed into an octagonal or other bar (called a loop), and which bar may be then or at any time heated in a fire, and worked by the workman and forge hammer into rods or bars of iron, for various purposes. Or the cast iron or pig

[6] No. 1370. The title is "A new Method of Working and Refining Cast or Pig Iron, and converting the same from a Fluid State into Wrought or Bar Iron, which would be of Publick Utility."

metal may be worked or refined from the pig iron, or when in a cold state, as follows:—The refining furnace being heated, as above described, the cast iron or pig metal is placed in the furnace on the place prepared for it (as described in the Plan), and the fire excited by the blast of air till the metal is in fusion, and then the opperation through the whole process is the same as above described. . . . .

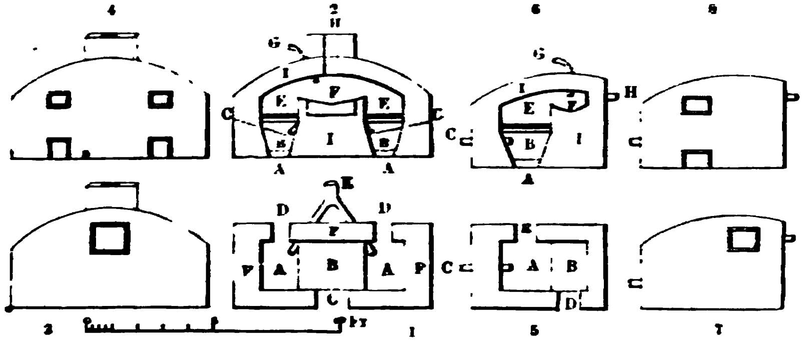


Fig. 131. Engravings accompanying Peter Onions' specification.

"The reference to or description of the Plan of the refining furnace. marked A.—Figure 1, the ground plan: A, A, two fireplaces; B, the inside of the furnace; C, the door place; D, D, two doors to put the fuel in at; E, the air blast pipe; F, the foundation or walls. Figure 2, profile and section of the inside of the furnace: A, A, a cistern or trough of water; B, B, the space below the grate for the ashes; C, C, air pipes from the blowing machine; D, D,* the fire grate; E, E, the spaces for the fuel; F, the place to receive the pig metal; G, a pipe to convey cold air occasionally; H, the vent or chimney; I, I, I, the arch and other part of walls. Figure 3, the front view, with the door in which to put the metal into the furnace. Figure 4, the back view, with two doors to receive the fuel, and two doors to take the ashes out. Figure 5, ground plan of a small furnace: A, the plan for the fire; B, the place to receive the pig metal; C, C, the air blast pipe; D, the door for the metal; and E, the door for fuel. Figure 6, section of the inside of the furnace: A, the water trough; B, the space for the ashes: C, C, the air pipe from the blowing machine; D,* the fire grate; E, the space for the fire grate; F, the place for the metal; G, the cold air pipe; H, the vent for the hot air. Figure 7, the front view, with the door for the metal, the air pipe, and vent. Figure 8, the back view, with the door for the fuel, and a door to take the ashes out at."

That the process of puddling is described in this specification, and that it was conducted on the bed of a furnace to all intents and purposes reverberatory, heated by flame evolved from fuel contained in a separate fireplace or separate fireplaces adjoining, there can be no doubt whatever. It is true that a blast was injected under the grate to promote the combustion of the fuel, and another blast directed upon the surface of the molten pig-iron; but this in no way affects the

* There is no space for the insertion of these letters, but the part will be easily recognised.

question. The process specified by Onions was essentially that of puddling; and nothing can be more graphic than the description which he gives of the "coming to nature" of the iron, and the formation of cinder; and I can hardly conceive that such an account could have been drawn up except by an eye-witness of the process in operation. Cort's claim to be regarded as the original inventor of puddling is thus further invalidated by the specification of Onions' patent. There is, however, one point of difference, and it is this, that Cort substituted a chimney, as a means of causing the draught of the furnace, for the blowing apparatus of Onions; and in so far his process is more simple, though certainly not more effective, than that of his predecessor. Still it is somewhat singular that in recent years even the blast should have been used in certain localities as an accessory to the chimney.

The statements and opinions inserted after Mr. Homfray's evidence were not submitted to the Parliamentary Committee of 1812, which disputed Cort's claim to originality in the matter of these inventions; and it is alleged that the Chairman of that Committee, on reading it after the Report had been made, acknowledged that if it had been duly presented to the Committee, their decision would have been entirely opposite.

It should be added that Cort never received one farthing from Mr. Richard Crawshay by way of royalty. The patent having been locked up by the Government for Jellicoe's debt, the rights were deemed extinct. The patent for grooved rolls expired in 1798, and it is computed that previously Mr. Richard Crawshay had manufactured not less than 50,000 tons of rolled iron, on which the royalty would have amounted to 25,000*l.*

Some persons may think that I should have devoted less space to the consideration of Cort's case, but I could not have done so with justice to the subject. His story is peculiar, and one of the saddest in the annals of invention. Its interest depends on the truth of certain statements, of which some, as we have seen, were not only doubted, but repudiated, by a Committee of the House of Commons. These statements, it seems to me, have since been clearly established on documentary evidence quite unassailable. That evidence is before the reader, who has now the same means of forming a judgment as the author, whether Cort deserves to rank as an inventor, whether he has a claim upon our sympathy as the victim of injustice, and whether those who gained largely by the adoption of his processes did not act towards him in a manner of which most men would be ashamed.

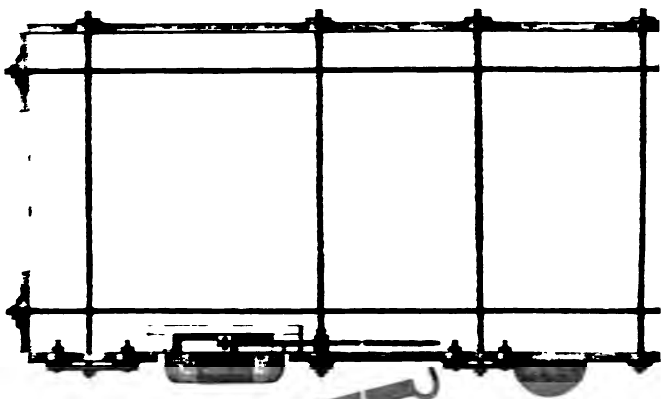
It is true that the value of the process of puddling has been greatly enhanced by subsequent improvements, especially two, viz. the application of iron bottoms to the puddling furnaces, and the boiling process. But this has been the course with many inventions, perfection only being arrived at by slow degrees; and merit is not the less because others subsequently appear who improve the methods of their predecessors.

[illegible]

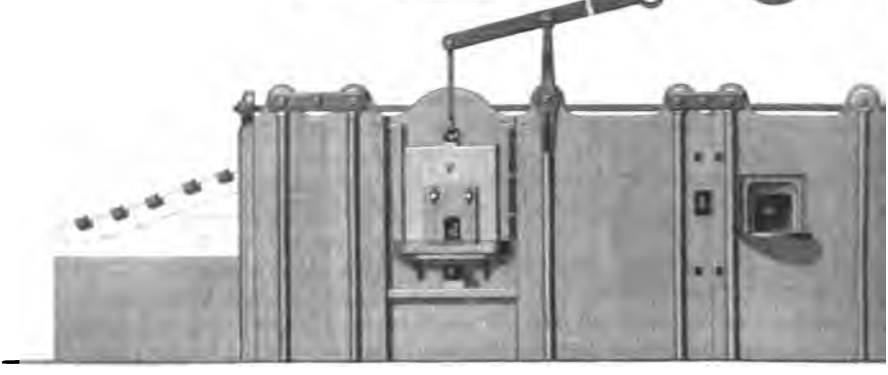
[illegible]—The [illegible] which I have selected for description [illegible] at the Bromford Iron Works, near Birmingham, belonging to my friend Mr. W. H. Dawes. The accompanying engravings, figs. 132, [illegible] have been [illegible] by my friend Mr. C. [illegible] the [illegible] manager of the works, to whom I am further indebted for valuable information on many points relating to the manufacture of iron. I may also state that I spent nearly a week in measuring and drawing the [illegible] employed in its construction.[7] By carefully studying and comparing the engravings, the reader will [illegible] description.

The puddling-furnace is reverberatory, and has a very large fire-place, compared with the size of the bed.

[illegible] The fire-hole.—There is no door, the hole being closed by



Plan of the top.



Side elevation.

Fig. 132.

[7] There is a model of it to scale in the Royal School of Mines, made by the pattern-maker at the Bromford Works. It may be taken to pieces, and every casting is represented.

coal piled upon the projecting ledge at the bottom. In some furnaces the fire-hole or stoke-door is on the side opposite to that on which the puddler works, and in others it is at the end of the fire-place.

b, 132, 134. Small hole, termed staff-hole, through which the puddler heats his staff, a wrought-iron bar about 1¼ in. square, welded to the ball, and used for manipulating it under the hammer, etc.

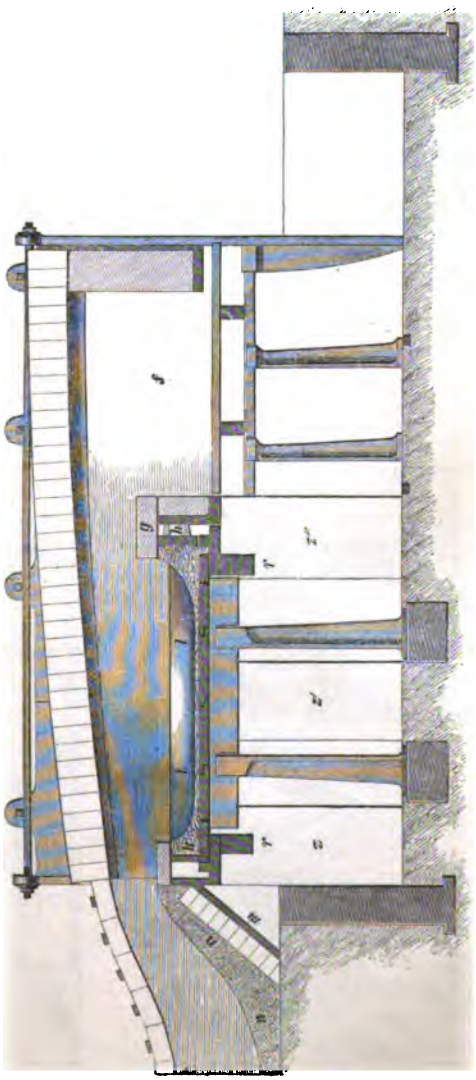


Fig. 133. Longitudinal Vertical Section through the middle of the frame.

c, 132. Door. It consists of a frame or shallow box of cast-iron, which on the inner side is filled in with fire-brick; and there is, as it were, a second smaller door, attached in the manner shown, but this is now pretty generally dispensed with. The door is raised or lowered by a counter-poised lever. It is only opened to introduce the charge and draw out the balls. During the working it is firmly fastened by driving in an iron wedge between one side of it and the door-frame.

d, 132, 139. Hole at the bottom of the door through which the puddler works the metal in the furnace.

e, 132, 139, 147. Tap-hole, through which the slag, technically termed tap-cinder, is let out, and which during puddling is stopped up with sand.

f, 133. Fire-place. This as well as the arch and sides above the bed are built of Stourbridge fire-bricks. The bricks forming the outer end of the fire-place are supported on an iron casting. The sides rest on

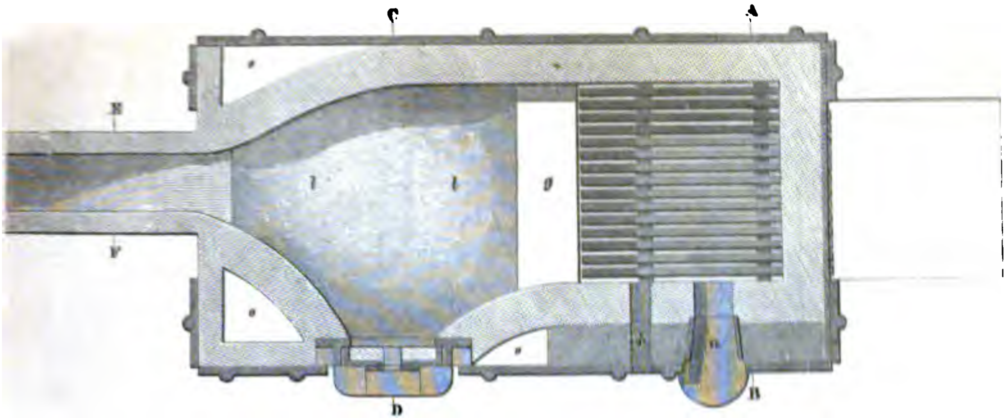


Fig. 134. Horizontal section above the fire-bridge, showing the plan of the bed.

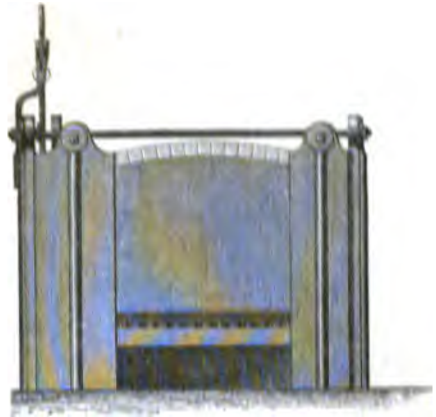


Fig. 135. Elevation at the fire-place end.

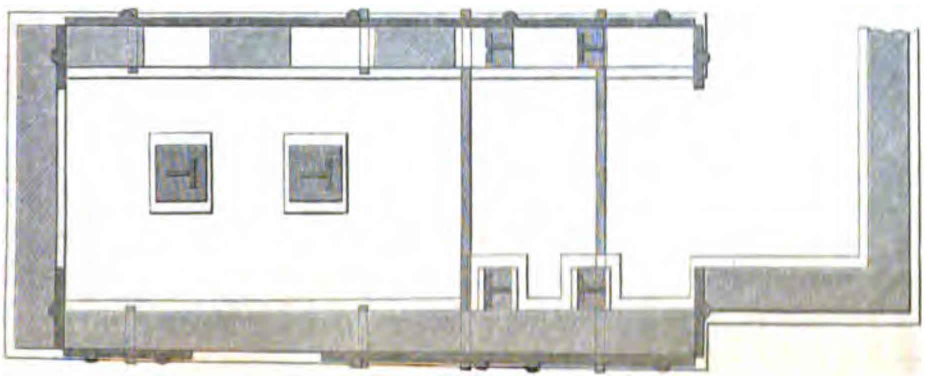


Fig. 136 Plan of foundations.

Fig. 137. Vertical section through the flue on the line E F, fig. 134, showing also the end elevation near the stack.

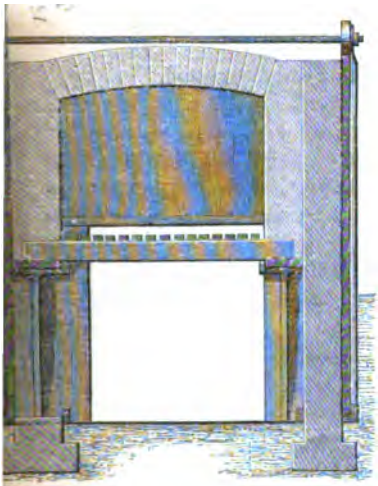


Fig. 138. Vertical section on the line A B, fig. 134.

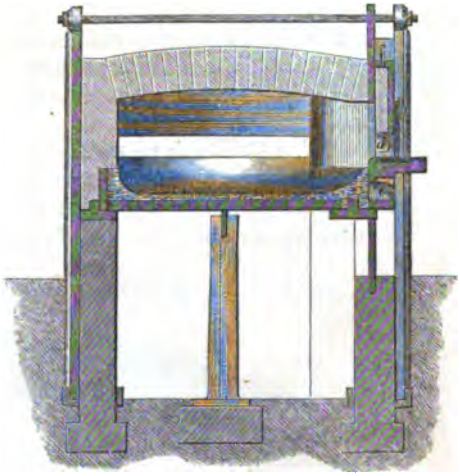


Fig. 139. Vertical section on the line C D, fig. 134.

cast-iron bearers, supported on cast-iron standards. Extending across at the fire-bridge is the fire-bridge plate of cast-iron.

g, 133, 134. Top of the fire-bridge, formed of slabs or quarries of fire-brick. Upon it, towards the end farthest from the working side, a little pier of loose fire-bricks is piled, called the "monkey" in South Staffordshire, and which is intended to deflect the flame towards the door *c*.

h, 133. Channel through which air circulates in order to keep the fire-bridge cool.

i, *i*, 133. Bottom plates of cast-iron, of which there are four (see the special description of figs. 140 and 141).

k, 133. Layer of broken up roasted tap-cinder called "bull-dog," which extends round the side-plates surrounding the bed, and more or less over the bottom-plates.

l, *l*, 133, 134. Cavity constituting the bed proper of the furnace, in which the pig-iron is melted and manipulated. The bottom should be covered with a layer of oxide of iron 2 in. thick, formed by working up scrap-iron in the furnace.

m, 133. Cast-iron plate supporting the fire-bricks at the bottom of the flue, through which the products of combustion pass from the body of the furnace into the stack.

n, *n*, 133, 137. Layer of cinder which has run over and accumulated.

o, *o*, *o*, 134. Empty spaces.

p, 140. Back part of the bottom frame.

q, 140. Front part of the frame.

r, *r*, 133. Cast-iron bearers extending across the furnace and supporting the ends of the frame respectively.

s, 141. Back wall plate near the fire-bridge end.

t, 141. Back wall plate curved near the flue-end.

u, 141, 142. Plate at the fire-bridge end called the fire-bridge plate.

2 T 2

w, 140, 141. Plate at the flue-end called the flue-bridge plate.
x, 140, 143. Jamb-plate at the angle at the flue-end.
y, 140, 144. Jamb-plate at the angle at the fire-bridge end.
The side-plates x y are shown foreshortened as when set in the frame.
z, z', z', 133. Brick piers of common brick.
The stack, with its damper on the top, is shown in the engravings of the puddling-furnace to be next described. The damper plays an important part in the operation of puddling.

Special description of the frame, door-frame, fore-plate, and tap-hole plate.

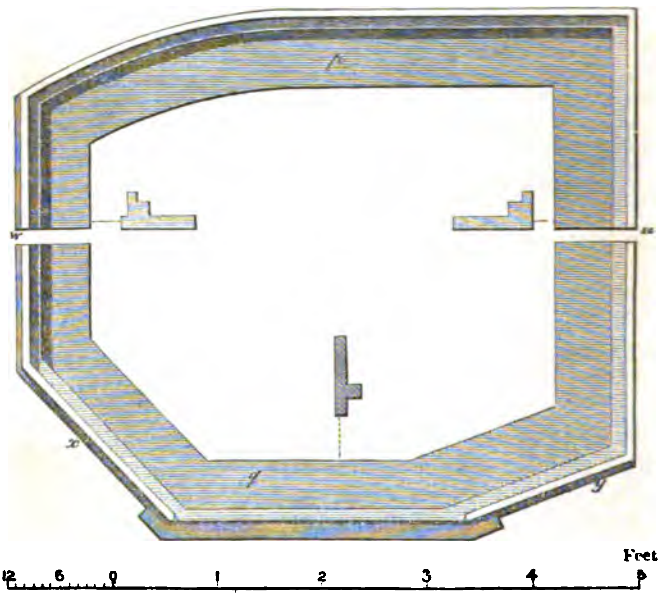


Fig. 140. Plan of the frame.

It is of cast-iron, and is in two pieces. It receives 4 cast-iron plates, which form the bed: they should not exceed $1\frac{1}{2}$ in. in thickness; they lie transversely on the broad surfaces, fig. 139. They are further supported underneath by a bar of wrought-iron on edge, resting on two cast-iron standards, as shown in figs. 133, 139. It is desirable that these standards should be placed nearer the door than is shown in the engraving, in order the better to support that part of the bottom upon which the pig-iron chiefly falls during the operation of charging. It also receives 6 side-plates of cast-iron set vertically. At the back, opposite the working door, are two of these plates, fig. 141, s, t, one of which, t, is curved; two fit into the fire-bridge and flue-sides, and the remaining two jamb-plates into the straight portions on each side of the door respectively. These plates are bevelled at the edges, which come in contact at the angles of the frame as shown in fig. 141.

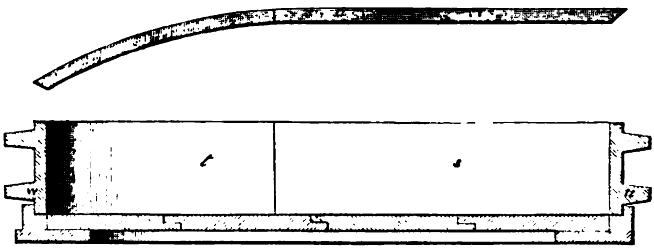


Fig. 141. Vertical section of the frame through the junction of its component pieces.

The fire-bridge and flue-bridge plates have snugs cast on their external surface, in order to prevent their being pushed outwards.

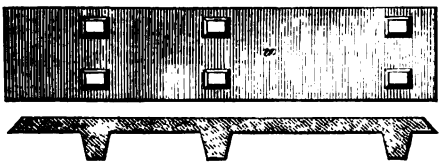


Fig. 142. Fire-bridge plate. See figs. 140, 141, *u*.

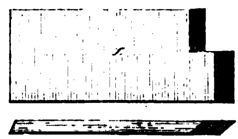


Fig. 143. Jamb plate at the flue side angle, or on the left hand of the door, *c*. See fig. 140, *x*.

The plates were formerly made to drop in *between* the ends of the bottom plates and the frame, and were liable to become so firmly wedged in as to render it difficult to withdraw them for repairs, etc. This and the preceding plate are shown foreshortened, as when set in the frame.

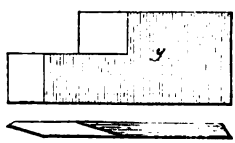


Fig. 144. Jamb-plate near the fire-bridge angle, or on the right hand of the door, *c*. See fig. 140, *y*.

Fig. 145. There are two vertical ribs, between which the door slides up and down, and which are strengthened with short cross ribs, somewhat broader at the base than elsewhere. The bottom end of one side of the frame is shown to the right, and from this the degree of projection of the vertical and cross-ribs may be found.

Fig. 146 a, side elevation; and β, upper surface. A piece termed the fore-plate bit, γ, of hard white cast-iron, let in on this surface, so as to be prevented by a projecting piece on each side from sliding out, and yet be capable of easy renewal. Over the fore-plate bit the puddler works his tools, and

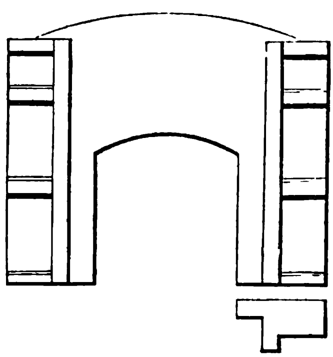


Fig. 145. Outside elevation of door-frame, which is made of cast-iron.

there is, necessarily, great wear of the iron on that part. The inner edge of the fore-plate bit is curved, as shown in β, and serves especially as the fulcrum for the tool. The door-frame rests on the sides of the fore-plate.

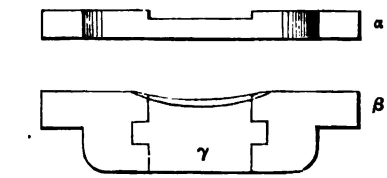


Fig. 146. Fore-plate of cast-iron.

Fig. 147 δ, upper surface; ϵ, side elevation; ζ, vertical section through e, the tap-hole. The fore-plate rests on the top of this plate.

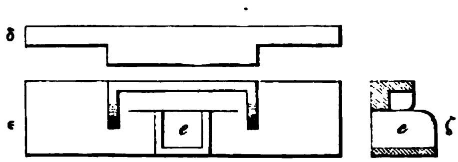


Fig. 147. Tap hole plate or breast-plate.

The sides and ends of the furnace are firmly supported by cast-iron plates connected at the top by wrought-iron tie-rods, as shown in figs. 132, 133, 135, 137, 138, 139; and at the bottom by wrought-iron clips and bars, as shown in fig. 136. The whole of the interior under the bottom is open for the free circulation of air. Below the tap-hole is a cast-iron plate at the back, so that the tap-waggons, in which the cinder is removed, are prevented from running too far underneath.

In the special description of the frame, etc., it will be observed that some minor details are not exactly as represented in fig. 133; but this is comparatively unimportant.

In one of the puddling-furnaces which I saw at the Bromford Iron-works, the plates at the flue and fire-bridge ends contained coils of wrought-iron tubing, through which water circulated. They were made like the water-tymps previously described, and were reported by Mr. Arkinstall to answer well.

Any other details which may have been omitted in the description will, it is apprehended, be clearly intelligible from the engravings.

The tools with which the molten pig-iron is manipulated are, in South Staffordshire language, the rabble and the paddle. The rabble is a strong wrought-iron bar, of which about half is square in section, and the other half, which is grasped by the puddler, circular; and the square end is welded to a piece of flat-iron about $2\frac{1}{2}$ in. broad, which is bent at right angles, forming the working point. It is about $1\frac{1}{4}$ in. square and 8 ft. long, and weighs about 40 lbs. The paddle is another similar, but somewhat less, heavy bar of wrought-iron, bevelled off at the square end into an obtuse chisel-like edge. The rabble and paddle are alternately used for stirring and otherwise working the iron. Each puddler has several of these tools, which are cooled, as occasion may require, by plunging them into water contained in small cast-iron cisterns called water-boshes.

Small hopper-like boxes, made of wrought-iron, on wheels, called tap-waggons, are placed under the tap-hole during tapping to receive the molten cinder, which speedily consolidates and is then wheeled away.

A puddling-furnace usually lasts about six months, when it must be rebuilt; but needs repairing every week. The cost of an ordinary puddling-furnace may be reckoned at about 130*l.*; with good workmen the bottom plates will last two or even three years, but bad workmen will spoil them in a month. They become quite tough in the course of about six weeks' working. There are about 1500 fire-bricks in one furnace. When the South Staffordshire New Mine coal (*i. e.* the variety occurring in the vicinity of Bromford) is used, the grate is made large. With this coal the bars clinker much sooner than with the Thick-coal. The dimensions of the grate will be found to vary somewhat in different localities, according to the kind of coal employed.

South Wales.—I have selected for illustration one of the furnaces belonging to the Ebbw Vale Iron Company, to whom I am indebted for the admirable drawings from which the accompanying engravings have been executed, from fig. 148 to 155 inclusive. After the pre-

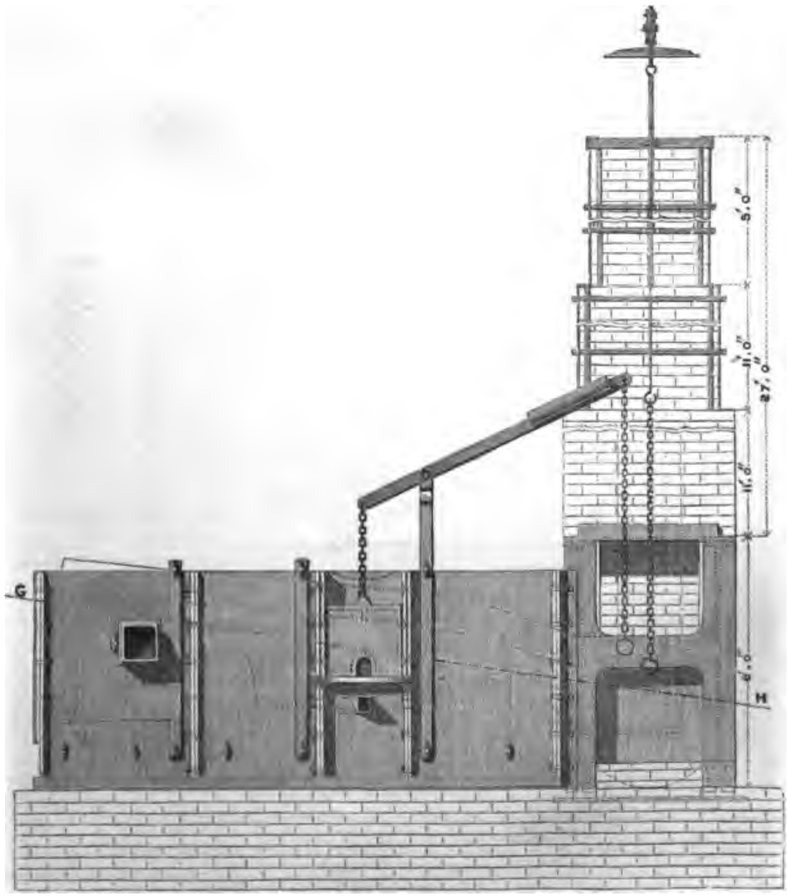


Fig. 148. Puddling-furnace, Ebbw Vale. Side elevation.

ceding detailed account, a few explanatory remarks only will be needed. Cast iron, it will be observed, is extensively employed in its construction. The bed is formed of cast-iron plates, but the mode in which they are fixed and supported differs from that in the South Staffordshire furnace. The bottom plates rest on cast-iron bearers, the ends of which are supported on side brackets. Under the hollow cast-iron bearer below the fire-bridge is a flat wrought-iron bar, and another

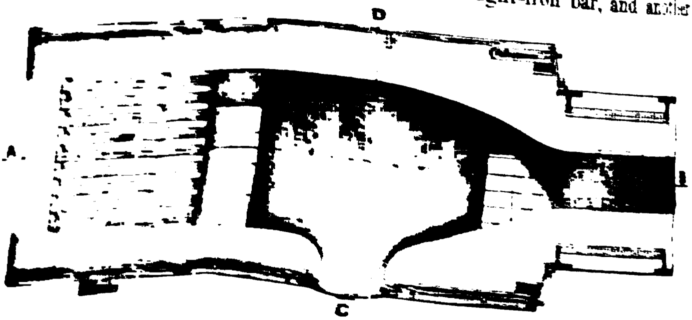
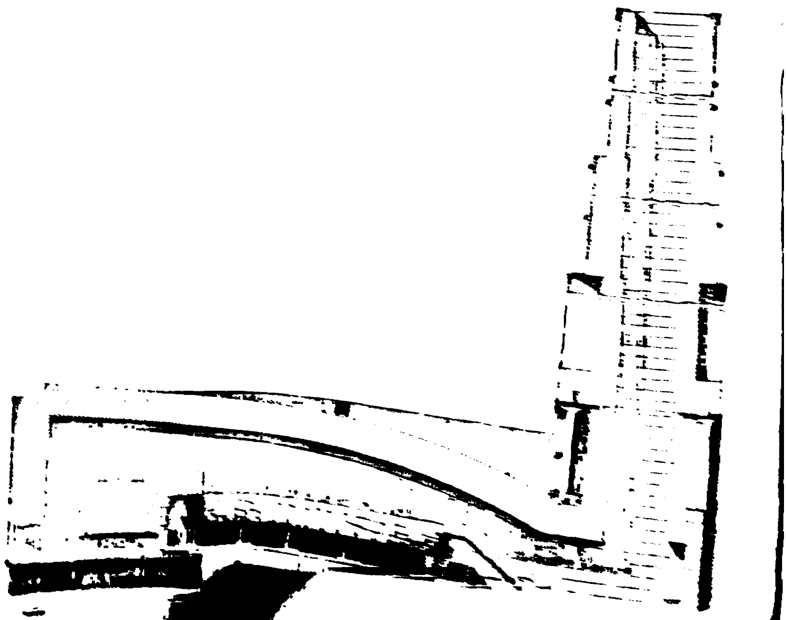


Fig. 149. Section on the line G H, fig. 148.



imilar one under the corresponding bearer [illegible] fig. 150. There [illegible] each side, and [illegible] 155, in which [illegible]

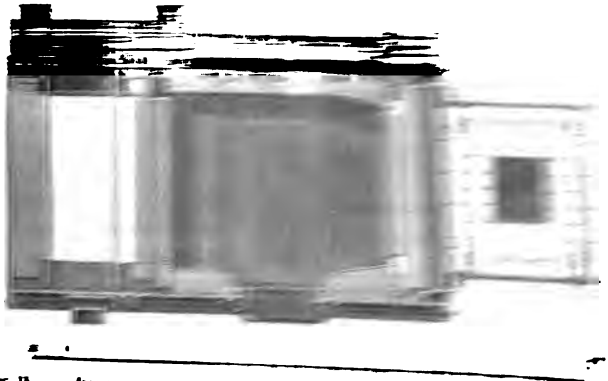


Fig. 15[illegible]. [illegible]

...ction on the line E F, fig. 158

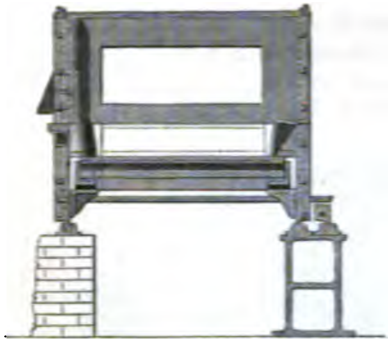


Fig. 154. Vertical section on the line E F, fig. 151.

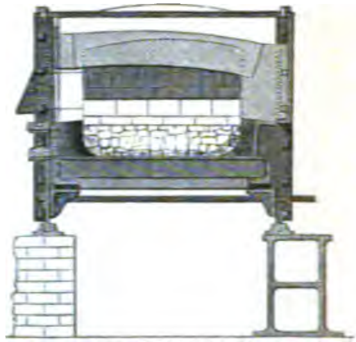


Fig. 155. Vertical section on the line C D, fig. 149.

Puddling-furnace, of which the sides of the bed are cooled by the circulation of water.—I am indebted to Mr. Levick for drawings of one of these furnaces at Blaina. The sides of the bed are formed partly of solid plates and partly of hollow castings, through which water is kept flowing. In other respects the construction is similar to that of the Ebbw Vale furnace. The engravings, from fig. 156 to 160 inclusive, will explain themselves sufficiently without further description.

a, a, a, 157. Hollow cast-iron sides of the bed. *b,* 157, 158. Fire-bridge.
c, c, 157, 158. Bottom-plates of cast-iron.
d, 157. Wrought bars supporting the bottom-plates.
e, e, 157. Transverse cast-iron bearers carrying the bars *d.*
f, 157. Side-brackets of cast-iron supporting the bearers *e, e.*
g, 157. Cast-iron plate.
h, 157, 158. Grate-bars of wrought-iron.
i, 157. Cast-iron bearer carrying the end wall of the fire-place.
k, 156, 158. Fire-hole.
l, l, l, 157, 158. Outside plates of cast-iron.
m, 156, 158. Tap-hole.
n, n, n, 156, 158. Pipes connected with water boxes.
o, o, o, o, 157, 158. Cast-iron standards carrying the stack.

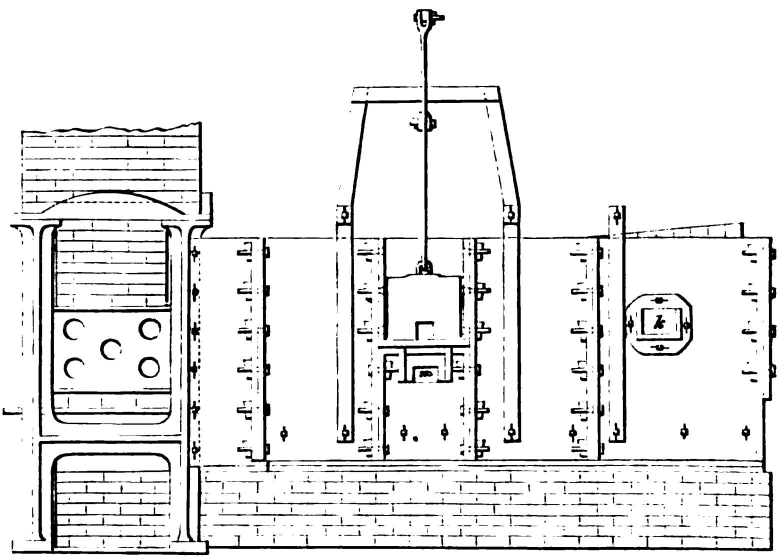


Fig. 156. Puddling-furnace at Blaina. Side elevation.

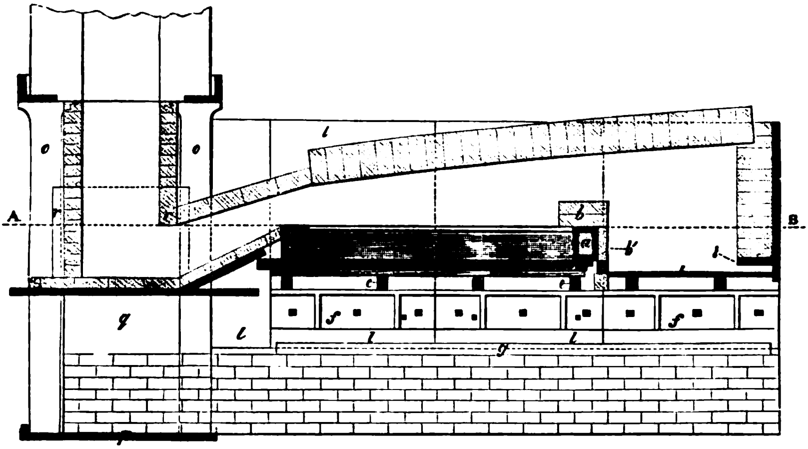


Fig. 157. Vertical section on the line G H, fig. 158.

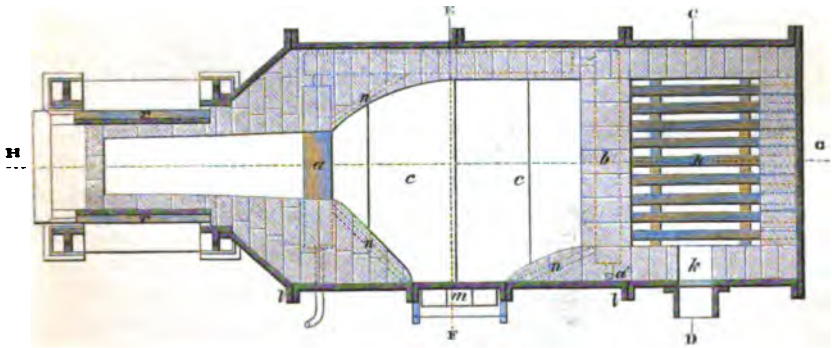


Fig. 158. Horizontal section on the line A B, fig. 157.

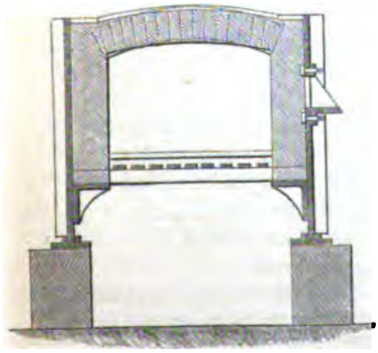


Fig. 159. Vertical section on the line C D, fig. 158.

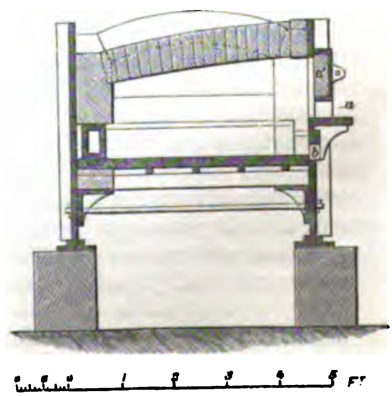


Fig. 160. Vertical section on the line E F, fig. 158.

Invention of iron bottoms.—The bed of the puddling-furnace introduced by Cort was made of sand, and continued to be so made until about the year 1818, when Mr. Samuel Baldwyn Rogers, of Nant-y-Glo, Glamorganshire, substituted the "iron bottom" with great advantage. The invention was not patented.[8] A bed of sand must be subject to great corrosion from the oxide of iron formed during the operation; and this will cause considerable loss both of time and money in necessary repairs, and, consequently, render the furnace less productive in a given time. It may, moreover, be readily conceived how liable to injury such a bed must be from the manipulations of puddling to be presently described.

Mr. Rogers declares that in the year 1818 he freely offered his invention of iron bottoms to Mr. A. Hill (Plymouth Iron-works), Mr. Forman (Pendarren), Mr. Hall (Rhymney Iron-works), Mr. Homfray (Tredegar), and Mr. Crawshay (Cyfartha), and that these gentlemen received it with "sneers and ridicule," pronouncing it impossible of realization. However, Mr. Richard Harford, then of the Ebbw Vale Iron-works, adopted it, and not many years afterwards iron bottoms came into general use. Mr. Rogers alleges that, whereas in 1818 it was considered that "8 tons were a good weekly yield from a furnace," the effect of his invention has been to increase the weekly yield of a furnace to 20 or 24 tons.[9] It is admitted by Mr. Rogers that his original proposition was to use a flux in conjunction with iron bottoms, which "would enable the puddler to obtain *any quality of result* from his furnace that may be desired;" and he states that this part of his invention was partially carried into practice by the late Mr. Harford at the Ebbw Vale Iron-works. He gives the following receipt for a flux, "should a *cold-short* bar be desired:"—

"Common salt	$7\frac{1}{2}$	lb.	Crushed to powder.
Nitre	$\frac{1}{2}$	,,	
White fire-clay	4	,,	Dried and ground fine, and all the materials well mixed up together."[1]
Oxide of manganese	8	,,	
Best hæmatite iron-ore	16	,,	
Unslaked lime	10	,,	
Charcoal powder	12	,,	

Mr. Rogers declares that his "fluxes were recommended to the iron-trade, and actually used at several large iron-works, as far back as the year 1818;" and hence, he properly remarks, "they cannot possibly be reckoned in the category of *piracies* or *imitations* of inventions or discoveries of comparatively recent dates." He further calls attention to the fact that common salt, nitre, oxide of manganese, fire-clay, and hæmatite had been recommended in puddling by the late Mr. Mushet more than 40 years ago [from 1858].[2] But it might be added that the use of some of these so-called fluxes is long anterior even to Mr. Mushet's recommendation. I have previously inserted an extract from the spe-

[8] An Elementary Treatise of Iron Metallurgy. By Samuel Baldwyn Rogers. London, 1858, p. 227. I have been careful, as far as possible, to verify, by information from various sources, the correctness of Mr. Rogers's statements respecting the history of his invention.

[9] Op. cit. p. 226.

[1] Op. cit. p. 241.

[2] Op. cit. p. 246.

cification of John Payne's patent for improvements in the manufacture of iron, A.D. 1728, in which he claimed the use of wood-ashes, glass, sandiver ["glass-gall," or saline matter, such as alkaline chlorides and sulphates, which appear on the top of the glass after complete fusion], common salt, clay, kelp, and potashes. In an interesting specification of a patent granted to John Wood, A.D. 1761, lime, kelp, and "soaper's waste" are claimed as fluxes for effecting the conversion of granulated pig-iron into malleable iron.[3] Again, in the specification of a patent granted to James Goodyer, A.D. 1771, it is stated that the addition of "salt [common] and other saline substances," and animal or charcoal dust, improves steel.[4] These extracts, on the use of saline fluxes, have a signification which will be appreciated in the sequel.

In reference to the question of the invention of iron bottoms, a patent granted, A.D. 1788, to Robert Gardner, described as "of the City of London, ironmaster," deserves careful attention. The title of the patent is, "A New and Peculiar Art or Method of Manufacturing Iron, Copper, and other Metals, by a New-invented Progressively Multiplying Air Furnace."[5] The essence of this invention consisted in passing the flame, etc., escaping from the bed of one reverberatory furnace, over another similar and contiguous bed, and from thence over a third, or even a fourth bed in succession. If the waste flame, thus applied, did not suffice to raise the temperature high enough, it was to be supplemented by a fire-place, etc. "By this means the division next to the fire being the hottest, gives the iron (if iron be the metal worked) what is termed a welding heat (if so great a heat is wanted), for either rolling or hammering, whilst the second division brings the iron to the highest degree of a red-heat, for the purpose of moving the various pieces in succession into the first; in doing of which a vast deal of time is saved, and great waste prevented, by avoiding the old method of putting a large quantity of cold iron into the furnace, and waiting until the whole is got up to a welding heat; which pieces being only worked off one by one, those that continue whilst the others are working waste in proportion to the time they remain in the fire. The flame, after leaving the second division, heats a third, or any number in progression, according to the degrees of heat which may be wanted, either for iron, copper, or any other metal," etc. "The second object of this invention is to prevent the destruction made in furnaces worked upon the old plan, in taking out the bottoms by the means of a cast-iron floor for laying the sand-bottom upon, and which floor is left hollow underneath, to prevent its melting, having a passage at the side for the discharge of scoria or dross, the floor being inclined that way to facilitate the discharge. By this method the sand bottom, when worn out, is easily taken off from the iron floor, without injury to the furnace." Again, in 1793, a patent was granted to William Taylor for "An Air Furnace on an improved Construction."[6] The furnace was made of brick, with cast and wrought

[3] Abridgments, etc. *ante cit.* p. 5.
[4] Ibid. p. 9.
[5] No. 1642.
[6] A.D. 1793, Nov. 6, No. 1966.

iron, and had two fire-places at each end communicating with a common stack. It had an iron bottom, covered with sand, and cooled underneath by a current of air. How far the inventions here described resemble that of Mr. S. B. Rogers, the reader will be able to judge for himself. Mr. Rogers died recently in absolute penury, and at the advanced age of 85. I have made particular inquiry concerning him. His character was unimpeachable. He was careless about money, fond of experimental chemistry in his own rough way, and devoted to music above all earthly things. He was a skilful fiddler, and he also composed music. He lived at a time when brandy-and-water was copiously and universally imbibed; but, although naturally of what is termed a jovial temperament, he avoided intemperance himself. The poor old man on his deathbed received pecuniary aid from Mr. Crawshay Bailey, whom he had so long and faithfully served; but other ironmasters who were appealed to on his behalf also rendered assistance.

Manipulation.—I know scarcely any metallurgical operation more interesting to watch than puddling. I will now present a detailed description of it, as I saw it practised by one of the best puddlers in South Staffordshire, at the Bromford Iron-works, in 1859. Dr. Beddoes presented to the Royal Society, March 24, 1791, a description of the process of puddling *grey* pig-iron from his own observations. The charge was 2½ cwts. The furnace had two chimneys, one at the end as at present, and another over the fire-place. Both had dampers. When the damper of one was up, that of the other was down, so that the flame might be made to pass over the bed or direct into the chimney over the fire-place. Dr. Beddoes' account is very circumstantial and correct. He especially dwells on the "fermentation" and the evolution of blue jets of flame over the surface. He has recorded one observation of interest, namely, that the metal at one stage became decidedly hotter after the flame had been turned off from the bed. He did not rightly interpret the fact, which is due to the heat developed by the combustion of the iron.

The side-plates are lined either with "puddling mine" (roasted red-mine, a black band from North Staffordshire—see Table of Iron Ores), or "bull-dog" (roasted tap-cinder), or with both, and the bottom is covered, as previously stated, with a layer of oxide of iron. The bull-dog is crushed between rolls; the large pieces are first put in and then covered with crushed mine or bull-dog; and the whole is plastered over with red hæmatite (of the unctuous or soft variety) made into a paste with water, and afterwards rammed well in. The brickwork at the sides is, as shown in the engravings, built to overhang the bed, whereby a space is left underneath for ramming in the mixture above-mentioned. In every turn or shift of 12 hours, about 1 cwt. of scrap wrought-iron is introduced into the furnace and worked into a ball, in order to supply a coating of oxide of iron over the bottom.

July 21, 1859.—The cinder having been tapped off, and the furnace being supposed to be ready for the next heat. The charge consisted

of a mixture of 1 cwt. of refined iron and 3 cwts. of forge-pig iron (long weight as usual), and about 1 cwt. of hammer-slag and iron-scale.

$1^h\ 50^m$. Hammer-slag was put in, and spread over the bed and round the sides. This charging was effected in about 3^m, the damper being up all the while. The door was let down and wedged, as before described, and the working-hole, or, as it is termed, the stopper-hole, at the bottom of it was closed up with a bit of bar-iron. The tap-hole was stopped up with sand. Coal was introduced, and the fire "fettled." Smoke and flame issued from the top of the stack. Nothing more was done until $2^h\ 9^m$.

$2^h\ 9^m$. The puddler's assistant or "underhand" put in coal. The puddler lifted or moved about the pig-iron through the stopper-hole with his paddle, which required about 2^m.

$2^h\ 15^m$. The underhand repeated the last operation of lifting or moving about the pig-iron, detaching any pieces which stuck to the bottom. This is done in order to allow the flame to play on all parts of the iron, the bottom of the furnace being the coldest part. Before withdrawing the paddle, it was struck with a hammer in order to knock off any iron adhering to it. Stirring and rabbling were constantly practised by the underhand.

$2^h\ 16^m$. The whole of the pig-iron was not yet quite melted. The molten portion "frizzled," as though in incipient ebullition. When near its melting point the pig-iron may be easily broken up.

$2^h\ 25^m$. The fire was replenished. The puddler rabbled constantly. All the pig-iron was completely melted. Up to this time the damper had remained up, but it was let down after the pig-iron had melted. The letting down of the damper will depend upon the temperature of the furnace. If the furnace is "very cold," the metal will "come up" without. [The meaning of this term will be understood from what follows.] The underhand stirred incessantly.

$2^h\ 36^m$. The fire was made up by the puddler, the stirring by the underhand having continued without interruption. The damper was raised.

$2^h\ 40^m$. The puddler, naked to his waist, took the rabbling in hand. The molten metal presented the appearance of full ebullition, technically termed "boiling," and was swelling up and rising rapidly, jets of blue flame escaping everywhere from its surface, and the metal being spurted up with considerable force, thus showing that the formation of carbonic oxide must take place deep below the surface, owing to the oxidation of the carbon in the metal by the oxygen of the hammer-slag or other oxidised products of iron. The paddle received a swinging movement from side to side, as well as backwards and forwards.

$2^h\ 43^m$. The molten metal was almost white hot, and had risen nearly to the stopper-hole.

$2^h\ 45^m$. The metal had not risen higher, but had become whiter and hotter by stirring. The damper had been up about 10^m. Coal was thrown in through the staff-hole.

$2^h\ 53^m$. The underhand took the paddle, the puddler having done

the work since the time of the last observation. Much of the iron had "come to nature," producing pasty masses in the liquid cinder. It is beautiful to witness this separation of the malleable iron.

2^h 56^m. The puddler worked again.

2^h 58^m. The underhand now worked.

2^h 59^m. The puddler resumed work, the damper still continuing up.

3^h 5^m. The first ball was taken out, the damper was partially let down, and the stopper-hole closed. The reason of this is obvious; for, as soon as the iron has "come to nature," oxidation must cause unnecessary waste. The body of the furnace should be full of smoky or reducing flame to prevent this effect.

3^h 6^m. The second ball was taken out.

3^h 9^m. The third ball was taken out.

3^h 11^m. The fourth ball was taken out by the underhand, the preceding ones having been withdrawn by the puddler.

3^h 13^m. The fifth ball was taken out.

3^h 14^m. The sixth and last ball was taken out, immediately after which the cinder was tapped off. A ball weighs about 80 lbs.

The puddler was one of the most, if not the most, skilful in the forge. He was about 38 years of age, and about 5 ft. 10 in. in stature. He complained that the work was much harder now-a-days than formerly, when not more than 2 cwts. or 3 cwts. of pig-iron were puddled at one heat; but Mr. Arkinstall assures me that this is entirely untrue, and that during the last thirty years the charge has never been less than 4 cwts. He, however, admits that the work is harder now than formerly in consequence of the pig-iron being more impure.

A good puddler would earn (July, 1859) 4*l.* 10*s.* for himself and underhand in a fortnight of 14 days, which includes 10 turns, *i. e.* 5 days and 5 nights of 12 hours each. Out of this sum the underhand received 2*s.* 6*d.* for each turn, *i. e.* a total of 1*l.* 5*s.* An extra sum was given to the underhand for "getting up" or heating the furnace in the first instance, thus raising the total to 1*l.* 7*s.* 6*d.*, so that the puddler would earn 1*l.* 11*s.* 3*d.* per week. In working an extra quality of metal, such as rivet-iron, which requires more attention, quick melting down, well working and careful balling, etc., 1*s.* per ton in addition was given, thus making an extra allowance of 5*s.* 6*d.* per week, so that the entire earnings of a good puddler at this kind of work would be 1*l.* 16*s.* 9*d.* per week. Puddlers vary considerably in skill, and between two puddlers in a fortnight there may be a difference of 10 cwts. in the yield of puddled bars. Most puddlers work until 50 years of age, and many even afterwards. Puddling is probably the severest kind of labour in the world; yet many puddlers attain the ripe age of 70 years, or more. The majority die between the ages of 45 and 50 years; and, according to the returns of medical men to the Registrar, pneumonia, or inflammation of the lungs, is the most frequent cause of their death. This is what might have been anticipated from the fact of their exposure to great alternations of temperature under the condition of physical exhaustion. Mr. Field, optician, Birmingham, informs me that puddlers are moreover liable to cataract,

induced by the intensely bright light of the furnace; that he has seen a great number of such cases, and supplied the patients with glasses.

It is important that the fusion of the pig-iron should take place rapidly, in order to avoid unnecessary waste; for if it be too slowly effected, in consequence of the temperature not being high enough, great scaling may occur, when, as the men say, they "can hear it frizzling." According to Mr. Arkinstall, if the furnace is worked "cold," the iron produced is generally red-short. To produce good iron the "boiling" must be conducted at a sufficiently high temperature. The temperature may be too low, either by closing the damper, or by defective construction, or by wearing of the furnace.

A ball withdrawn from the furnace before it has been sufficiently puddled, and which has in consequence to be put back into the furnace, is termed "a cobble," and the puddler who has produced it "a cobbler."

The hammer-slag employed is reported to be improved by keeping, and allowing it to become rusty.

The wind may have considerable effect on the working of the furnace; and according to the position of the furnace, with respect to exposure to wind, the size of the flue must be modified.

About 24 cwts. (of 120 lbs. to the cwt.) of South Staffordshire "Thick-coal" are required for 20 cwts. (of 112 lbs. to the cwt.) of puddled bar, and of "New Mine coal" about 2 cwts. additional; and there may be a difference of 2 cwts. in the amount consumed, according to the skill of the puddler.

Mr. Arkinstall states that 22 cwts., and sometimes only 21½ cwts., of pig-iron yield 20 cwts. of puddled bar.

The total time required to work off a heat varies from 1 hour to 1¼ or 1½ hour.

Refined iron is now only used at these works for the best qualities of hoop, bar, and other iron. Its effect is greatly to expedite the process of puddling; and in conjunction with it extremely grey pigs, which alone could not be profitably treated, may be worked with advantage.

In conducting the operation of puddling, Mr. Joseph Hall, a man of great experience in the manufacture of iron in South Staffordshire, enforces attention to the following rules:—"First charge the furnace with good forge pig-iron, adding, if required, a sufficiency of flux—increasing or diminishing the same in proportion to the quality and nature of the pig-iron used. Secondly, melt the iron to a boiling or liquid consistency. Thirdly, clear the iron thoroughly before dropping down the damper. Fourthly, keep a plentiful supply of fire on the grate. Fifthly, regulate the draught of the furnace by the damper. Sixthly, work the iron into one mass before it is divided into balls; when thus in balls, take the whole to the hammer as quickly as possible, after which roll the same into bars for mill purposes." [7]

At the Ebbw Vale Iron-works, for ordinary descriptions of iron, such

[7] The Iron Question, p. 27.

as is used for the middle of the pile in making rails, common white pig-iron, as it comes from the blast-furnace, is usually puddled in admixture with the same pig-iron refined, in the proportion of about half and half, or $\frac{2}{3}$ of the former and $\frac{1}{3}$ of the latter. The charge is $4\frac{1}{2}$ cwts., of 120 lbs. to the cwt. Hammer-slag and mill-scale (*i. e.* scale from the rolls) are added in variable quantity, according to the nature of the pig-iron operated upon. Six balls are usually obtained at a heat, and 7 heats are worked off in 12 hours; but with grey forge-pig only 6 heats, of 4 cwts. to the heat, are completed in the same time. With white pig-iron the cinder is only tapped off at about every other heat; and in working wholly with refined metal the cinder is generally not tapped off more frequently than once in a turn of 12 hours. This is owing to the fact that refined metal is nearly free from silicon; and the cinder is less fusible than that yielded by grey or white iron, and contains therefore a larger proportion of oxide of iron. In puddling refined metal in the same furnace during an entire week consecutively, the layer of cinder has sometimes become so thick that, after the furnace has cooled down, it has been necessary to cut it out, and form a fresh bottom in the usual way. With grey iron, on the contrary, the opposite condition is apt to occur; and there is difficulty in keeping the bottom covered with a layer of cinder sufficiently thick. With white pig-iron [*i. e.* of South Wales], which invariably contains more sulphur than grey pig-iron, it is necessary that the balls should be at a very high temperature; for otherwise they would crumble to pieces under the hammer or squeezers. Accordingly in furnaces in South Wales, where such pig-iron is being puddled, those portions of the balls which stand out of the molten cinder may be seen glowing with intense whiteness, owing to the combustion of the iron, and which is not checked by putting down the damper, as it is essential to keep up the temperature very high. It is at this stage of the process that much waste may occur from the formation of oxide of iron resulting from this combustion. With grey pig-iron, on the contrary, containing less sulphur, this high temperature is not necessary, and the waste above mentioned may in a great degree be avoided by putting down the damper. I am informed by a friend of great experience in the manufacture of iron in South Wales, that the presence of a certain amount of phosphorus will enable balls, obtained from puddling white sulphury pig-iron, to be worked at a lower temperature, though the finished bar will be more brittle and tender when cold. This statement is founded on careful experiments on the large scale.

Theory of the Process of Puddling.

Supposing the pig-iron to consist only of carbon and iron, the object of puddling is the more or less complete removal of that carbon; and this is effected partly by the direct action of the oxygen of the air, and partly by the action of that contained either in the cinder formed, or the oxidized compounds of iron added, during the process. That the oxygen existing in this solid state of combination is powerfully ope-

rative in promoting decarburization of the pig-iron may be certainly inferred *à priori;* but the copious evolution, from the surface of the molten metal, of jets of carbonic oxide, which burn with the blue colour characteristic of that gas, and proceed from a considerable depth, as is proved by the spirting about of the metal, establishes beyond question the fact of the reaction between the carbon of the pig-iron and the oxygen of the oxidized compounds of iron, whereby carbonic oxide is formed with the reduction of an equivalent proportion of oxide of iron. The duration of the "boiling" stage coincides with the elimination of carbon in this gaseous state of combination.

In order to burn out the carbon, it is necessary at the same time, in this process, to oxidize a considerable quantity of iron; and in order that the pieces of malleable iron produced should be collected into balls, it is obvious that their surfaces, which are brought in contact at a high temperature for the purpose of welding them together, should not be coated either with infusible or difficultly fusible oxide; for in that case the interposed oxide would prevent *metallic* contact between the pieces of malleable iron, and, consequently, their welding together. Now silica, as we have seen, combines readily with protoxide of iron, and forms easily fusible silicates, with which two pieces of iron at a welding heat may be coated, and yet weld soundly together under pressure, the interposed liquid silicate being expelled in a greater or less degree, leaving *clean, bright* metallic surfaces of the metal to come in contact. The tribasic silicate of protoxide of iron has no action on metallic iron at high temperatures, and would indeed protect the surface from oxidation and keep it bright. Accordingly it is sought to produce in the puddling-furnace a silicate of this kind, which is termed "a welding cinder." Silica is supplied by the sand adherent to the surface of the pig-iron, when this has been cast in sand, by the materials of the bed of the furnace, and by the oxidation of the silicon in the pig-iron, which, as we have seen, often contains a large amount of that element.

We have hitherto considered the case of the decarburization of pig-iron, supposed to contain only carbon; but in the varieties of pig-iron actually treated in the puddling-furnace other elements generally or frequently occur, and these are silicon, sulphur, phosphorus, and manganese.

Silicon appears to be easily eliminated from pig-iron by the action of atmospheric oxygen on the molten metal. Price and Nicholson proved that in the operation of refining, silicon is oxidized before the carbon; and that practically the whole of the former might be separated in this process without the abstraction of any sensible amount of carbon.[*] Now in the process of puddling, silicon may be removed in like manner and in like degree. But several questions of interest here naturally suggest themselves. Is the silicon directly oxidized by

[*] Specification of Patent on the "Manufacture of Cast Iron." A.D. 1855, No. 2618, p. 4.

the oxygen of the air on the molten metal? Is silicon oxidized at a high temperature by the action of protoxide of iron, free or combined with silica, or by sesquioxide of iron? There can be no doubt that an affirmative reply should be given to the first question, the oxidation of the silicon being accompanied with that of the iron in a degree sufficient to form tribasic silicate of protoxide of iron with the silica generated. That silicon would reduce sesquioxide of iron at a high temperature to protoxide, with the formation of the same silicate of protoxide of iron, I have little doubt, though I have never made a direct experiment on the point. Whether silicon would, at a high temperature, reduce protoxide of iron free or combined, is more doubtful, and has not, so far as I am aware, been determined by experiment. I am, however, disposed to think that it will, but not the protoxide of the monobasic silicate (FeO, SiO^3).

Messrs. Calvert and Johnson, of Manchester, have investigated the chemical changes which pig-iron undergoes during its conversion into malleable iron in the process of puddling.[a] The carbon and silicon were determined in portions of the metal taken out at intervals in the course of one heat, and their results are presented in the following Table :—

	Time of taking out.	Carbon %.	Silicon %.
In the original pig-iron ...	..	2·275	2·720
Sample No. 1..............	12h 40m	2·726	0·915
,, 2..............	1h	2·905	0·197
,, 3..............	1h 5m	2·444	0·194
,, 4..............	1h 20m	2·305	0·182
,, 5..............	1h 35m	1·647	0·183
,, 6..............	1h 40m	1·206	0·163
,, 7..............	1h 45m	0·963	0·163
,, 8..............	1h 50m	0·772	9·168
Puddled bar 9..............	..	0·296	0·120

The pig-iron operated on was good No. 3 grey cold-blast Staffordshire. Its composition was as under :—

Carbon	2·275
Silicon	2·720
Phosphorus	0·645
Sulphur	0·301
Manganese and aluminium	traces
Iron	94·059
	100·000

The charge of pig-iron was 224 lbs., and before it was introduced the furnace "had been cleaned out with malleable scraps."

From the results above recorded, it would appear that not only is a large proportion of the silicon rapidly abstracted after the fusion of the pig-iron, but that there is also a considerable *absolute* increase in the proportion of carbon. If the silicon be first in great measure oxidized and separated as silica, which there is no reason to doubt, its removal must be attended with the oxidation and separation likewise of a con-

[a] Phil. Mag. Sept. 1857.

siderable amount of iron; and consequently there must be a corresponding *relative* increase in the proportion of carbon. This is very plain and intelligible; but the absolute increase in the proportion of carbon found greatly exceeds what may be accounted for in this manner, and I do not understand how it should have occurred. On this point Messrs. Calvert and Johnson remark, "The carbon had increased 0·625, or 21·5 % of its own weight, and the silicon had decreased in the enormous proportion of above 90 %. It is probable that these opposite chemical actions are due, in the case of the carbon, to the excess of this element in a great state of division, or in a nascent state in the furnace, and that under the influence of the high temperature it combines with the iron, for which it has a great affinity, whilst the silicon and a small portion of iron are oxidized and combined together to form protosilicate of iron, of which the scoria or slag produced during this first stage of puddling consists, and which plays such an important part in the remaining phenomena of the puddling process." This explanation, founded on excess of carbon in a "great state of division," or in a "nascent state in the furnace," is beyond my comprehension, and I must leave it to the reader to interpret it as he best can. It must obviously be very difficult in experiments of this kind to obtain anything like *fair average samples* for analysis, inasmuch as it is probable that the metal may not have precisely the same composition at one time in every part of the bed. Besides, in a reverberatory furnace, particles of carbonaceous matter are carried over in the rapid current of gaseous products from the fireplace, and some of these might easily vitiate the results by becoming entangled in the metal. I cannot suppose that Messrs. Calvert and Johnson should have been led into error from this cause, though it is well to bear in mind the possibility of the occurrence of such a cause of error.

At the beginning of the year 1859, M. Lan, Professor of Metallurgy at the School of Miners, Saint-Etienne, published a paper upon the reactions which occur in the conversion of pig-iron into steel and malleable iron in the charcoal finery, by what is designated the Rivois process, and in puddling.[1] He arrived at the same conclusion as Calvert and Johnson concerning the elimination of the silicon before the carbon; and he is careful to inform us that "analyses of the same kind, and leading to conclusions in part the same, have been made by Messrs. Crace Calvert and Johnson, and published in the *Annales de Physique et de Chimie*, in April, 1858, that is to say posteriorly to the commencement of my researches, and the confirmation of my first results." He further assures us that he began to study the reactions in question at the commencement of the year 1857; but the date of the beginning of Calvert and Johnson's investigation is April 4, 1856.[2] M. Lan has therefore no claim to priority over these gentlemen, and still less over Messrs. Price and Nicholson, who stated the fact in the

[1] Ann. des Mines, 5. s. 15. 1re. Livraison, p. 85. Études sur les Réactions de l'Affinage des Fontes pour Acier ou pour Fer. Par M. Lan, ingénieur des mines, professeur de métallurgie à l'École des mineurs de Saint-Etienne.

[2] Phil. Mag. *ante cit.*

specification of their patent dated November 20, 1855, and sealed May 16, 1856. Some modern investigators would act more wisely in obtruding their claims of priority of so-called discoveries less pertinaciously upon the attention of the public, especially if, as in this instance, they have no foundation. They may rest assured that one day or other all such claims to originality will be carefully sifted, when the spurious will be distinguished from the genuine, and modest merit receive its just acknowledgment.

Four varieties of pig-iron were treated in the Rivois process, two of which were from Savoy, and two from Dauphiné. Lan has given the following determinations of the carbon, silicon, etc., which they contained per cent.:—

	I.	II.	III.	IV.
Carbon	5·17	6·00	4·85	4·80
Silicon	0·88	2·00	1·70	1·44
Manganese	3·40	3·00	2·52	2·41
Sulphur............	traces	0·48	0·50	0·17
Copper	traces	0·10 to 0·15	0·05 to 0·10	0·05 to 0·10

No. I. is described as No. 1 grey pig, termed "hot pig-iron," with large, loose, brilliant, graphitic grains; No. II. as No. 2 grey pig-iron, closer in grain and less graphitic; No. III. as mottled pig-iron; and No. IV. as white lamellar pig-iron, with large crystalline facets.

The per-centage of carbon in No. II. is very high, and Lan accounts for this on the supposition that the specimen prepared for analysis "doubtless contained some nests of graphite."

The mean composition of the charge of pig-iron was as under:—

	Per cent.
Carbon	5·23
Silicon	1·57
Manganese	2·73
Sulphur	0·30
Copper	0·05 to 0·10

Specimens were taken out of the hearth at successive stages—the first immediately after fusion of the pig-iron—and analysed. The percentage results are as under:—

	I.	II.	III.	IV.	V.
Carbon	5·65	4·25	5·60	5·04	3·36
Silicon.........	1·50	0·48	0·60	0·85	0·60
Manganese...	2·55	not determ.	0·36	2·51	not determ.
Sulphur	0·25	0·11	0·13	0·19	0·17
Copper.........	0·05 to 0·10	0·15 to 0·10	0·15 to 0·10	0·10	0·05

Immediately after melting down, the pig-iron appears to have become 0·42 % richer in carbon, and to have lost 0·07 % of silicon. This result certainly needs confirmation, "supposing," as Lan remarks, "that errors of analysis will not suffice to produce these differences." But No. III. analysis, when compared with No. II., is more puzzling, for the carbon in it actually exceeds that in No. II. by 1·35 %. No. III. also contains 0·12 % more silicon than No. II. The explanation proposed by Lan is, that the ladle used in taking the specimen No. III. may have plunged a little deeper into the melted pig-iron than in the

case of No. II.; for "the analysis of No. IV., for example, shows that at a slight depth below the surface of the bath the pig-iron remains nearly the same as when first fused." Lan alludes to these differences as slight ("*petits écarts*"), but I confess that to me they appear considerable. Now if the bath of molten metal may thus vary sensibly in composition in different parts, what satisfactory result can be expected from the analysis of a portion taken out by a ladle, which, if immersed say an inch more or less, will remove metal differing sensibly in composition? The suggestion of Lan himself as to this source of error, and which he very properly raises, is sufficient to shake our confidence in the value of his analytical results.

Lan conducted other experiments to determine the changes which take place during the conversion of pig-iron into puddled steel, and found that the greater part of the silicon was abstracted before the removal of any of the carbon, just as in the Rivois charcoal finery.

With regard to sulphur, its elimination in the puddling-furnace is always, so far as my knowledge extends, very imperfect. It may possibly be oxidized by the oxygen of the air, or by that contained in the oxidized compounds of iron present; but some of it appears to pass into the cinder in the state of sulphide of iron, as sulphuretted hydrogen is often unmistakably evolved from tap-cinder by the action of hydrochloric acid.

Phosphorus is certainly separated in a considerable degree from pig-iron in the process of puddling, and may be found in the cinder as phosphoric acid in combination with protoxide of iron. I think it possible that some of it may pass into the cinder as phosphide of iron. It exists in the pig-iron as phosphide of iron, dissolved or diffused. Phosphide of iron containing, or in contact with, a large excess of iron, would be oxidized at a high temperature by the oxygen of the air, forming phosphate of protoxide or sesquioxide of iron, or a compound or mixture of these phosphates, the excess of iron being supposed to be likewise oxidized. I do not certainly know what action takes place at a high temperature between phosphide of iron and the oxides or silicates of protoxide of iron. These are points which require investigation.

There is, however, one fact in connection with this subject of the highest practical importance, viz., that when air is blown through molten pig-iron, as in Bessemer's process to be described in the sequel, silicon and carbon may be completely removed, while scarcely any of the phosphorus escapes. So small, indeed, is the amount of phosphorus separated in this process, that the resulting decarburized and desiliciurized *molten malleable* iron contains more phosphorus than the original pig-iron. I ascertained this fact in 1856 immediately after Mr. Bessemer showed me his process in operation at Baxter House, when I took specimens both of the iron and cinder, which were analysed in my laboratory by Mr. Dick. The iron contained 1·13 % of phosphorus, and the accompanying cinder only 0·34 % of phosphoric acid. The correctness of these results has since been amply confirmed, as will hereafter be shown. Now, in the operation of puddling the

results are precisely the reverse: for the malleable iron produced contains much less phosphorus than the original pig-iron, and the accompanying cinder a comparatively large quantity of phosphoric acid, say from [illegible] to [illegible] or more. Hence it is clear, that by the direct action of the oxygen of the air upon molten pig-iron, or even molten malleable iron, phosphorus is not eliminated in a sensible degree. To what, then, are we to ascribe the opposite result, which occurs in the process of puddling, in which there is powerful oxidizing agency at work? Is it due to the effect of the liquid cinder? Although I cannot answer these questions in a satisfactory manner, yet I will venture upon a conjecture, which I have long regarded as at least plausible.

In the puddling-furnace the iron as it "comes to nature," separates in a semi-solid or somewhat pasty state, and is not molten, as it is in Bessemer's process, the temperature in the former case being much below that in the latter, in which intense heat is developed by the actual combustion of iron. Owing to the formation and persistency of these pasty lumps in the puddling-furnace, which when collected into balls extend considerably above the surface of the bath of cinder, opportunity is afforded for the liquation or sweating out of any fusible compounds of iron, such as phosphide; and it is in this manner that I conceive the removal of the phosphorus may in great measure be effected. The following fact, confirmed by the experiments of my friend, Mr. Abel, at the Royal Arsenal, Woolwich, would seem to favour this view. When pig-iron, containing phosphorus in sensible quantity, is remelted and cast, that portion of the metal which solidifies last will be found to be richer in phosphorus than the other portion of the casting.

The elimination of phosphorus during the conversion of pig-iron into malleable iron is a problem of the highest practical importance in this and other countries, where the ores smelted for the most part contain phosphoric acid. We have seen that in the process of puddling a considerable amount of the phosphorus passes from the pig-iron into the cinder, the reverse of what takes place in the Bessemer process. These considerations suggested to Mr. Parry an ingenious method of producing iron practically free from phosphorus from *scrap wrought-iron*, such as the crop-ends of rails, etc., of which a large quantity is generally to be found in forges. The scrap is melted with coke in a cupola, having a particular arrangement of twyers, whereby it is rapidly converted, at the rate of about 1 ton per hour, into cast-iron, containing on the average 2 % of carbon. This cast-iron being derived from wrought-iron, is impregnated with only a small proportion of phosphorus; and, when re-puddled, the greater part of that phosphorus passes into the tap-cinder, thus yielding puddled bars practically free from phosphorus. Dr. Noad has examined the pig-iron so made, and was unable to detect in it the presence even of a trace of phosphorus. An armour-plate for ships of war has been manufactured with iron prepared by this process by the Ebbw Vale Iron Company, under Mr. Parry's supervision, and tested at Shoeburyness. A portion of the plate, examined in my laboratory, certainly contained phosphorus,

though in minute quantity. Mr. Parry estimated that this twice puddled iron might be produced at the cost of about 8*l.* per ton. The process has been patented by the inventor, and I present the following extracts from the specification, which will again be referred to under the head of Steel.[3] The cupola furnace resembles those which are commonly used in foundries for melting pig-iron, but in addition to the ordinary horizontal twyer, is a second smaller and opposite twyer, inclined downwards at an angle between 30° and 45°. It is by means of this inclined twyer that rapid carburization of the iron takes place.

"Sufficient fuel having been supplied to the furnace for the purpose of getting up the heat, I charge the furnace with about 7 cwts. of coke (with sufficient lime to flux the ash of the coke) to every ton of wrought iron, applying these materials in successive quantities of from 1½ cwt. to 1¾ cwt. of coke to 4 cwts. of iron, which will be found a convenient quantity for each charge. The converting furnace [*i.e.* the cupola] being filled and the blast put on, the furnace should be kept nearly full during the continuance of the operation, or the iron will not have taken up a sufficient dose of carbon, and unless this be done the subsequent treatment of the iron in the puddling-furnace will be useless; the presence of a certain amount of carbon in combination with the metal being necessary to produce the 'boil,' without which no efficient refining of the iron will take place. With a small furnace 2½ ft. square, rounded at the angles, and from 10 ft. to 15 ft. high, blown by one horizontal twyer having a nozzle of 2½ in. diameter, and one inclined twyer of 1¼ in. diameter; with a pressure of blast of 2½ lbs. to 3 lbs. on the square inch, I have been able to carburize and run out 1 ton of iron per hour. . . . . . . There is little or no loss of metal in carrying out this carburizing process when clean wrought-iron is employed; the small quantity of iron oxidized, and which passes off with the slag, being replaced by carbon. The minute portion of silicon in this carburized wrought-iron, as compared with that contained in crude pig-iron, does not admit of slag being formed to any extent when air is blown into it while in the fluid state; but the oxide formed would pass out at the top of the furnace as a dense brown smoke, and entail a loss, were it not that the column of incandescent fuel above reduces it to the metallic state and intercepts it. I find that a height of furnace from 8 ft. to 10 ft. is sufficient to effect this reduction, and prevent the loss of metal by sublimation. When the charge of scrap or puddled iron has been subjected to the blast a sufficient time to bring down, say a ton of the carburized metal, I tap the furnace, and run the metal into moulds as is usually done with pig-iron intended for puddling, and I otherwise treat it in a similar manner to iron prepared for puddling (that is to say). I now submit the carburized, wrought, or scrap iron to the operation of puddling in an ordinary puddling-furnace, and by that means cause it to give up

[3] Improvements in the Manufacture of Iron and Steel. A.D. 1861, Nov. 18th. No. 2900.

or part with the impurities remaining therein after the first puddling process. The metal I remove as puddled balls which may then be submitted to the ordinary rolls for the purpose of being reduced to the form of merchant or other bars. This completes in general the process of making my 'purified wrought-iron,' which may be subsequently converted into cast-steel, or applied to other uses. When, however, a still purer quality of iron is required, I repeat the converting or carburizing process, and then subject the metal to the puddling process as before. I would here remark that by taking the thoroughly puddled iron from the furnace in small balls or pieces, the cost of rolling the same into bars, and cutting those bars up by shears into pieces suitable for undergoing a second carburization, or for conversion into hard or soft steel, will be avoided. The pieces of wrought-iron intended for carburization should not be too large, not much exceeding the size of a railway bar cut up into lengths of 4 in. to 6 in. Cinder iron, of which nearly the whole of the railway bars laid down have been manufactured, becomes by sufficient carburization in my converting furnace, and subsequent puddling, equal in value to the best brands of mine iron, and may be used for the like purposes, or be converted into cast-steel; thus the iron rails now in use, as they successively become worn out, may by this invention be converted into durable cast-steel rails. . . . . From some years' experience in the analysis of irons, I have always found that the effect of puddling is to reduce the quantity of sulphur to about $\frac{1}{3}$, and of phosphorus from $\frac{1}{4}$ to $\frac{1}{5}$ of that originally contained in the pig-iron. It will thus be seen that when such purified iron has been sufficiently carburized in my converting furnace and again puddled, the impurities above named become almost entirely removed, and the iron is fitted for conversion into best cast-steel by this invention. I have found it desirable when using sulphury coke in the converting furnace, to add as much lime as the ash will bear, but not such an excess as to thicken the cinder and clog up the furnace. The coke should also when in a dry state be immersed in brine or a solution of carbonate of soda for a few days previous to use. The brine or carbonate of soda when thus intimately diffused through the whole substance of the coke will effectually seize the sulphur and carry it off in the slag, and thus prevent the contamination of the metal. Carbonate of soda or any other cheap alkali (in a dry state) may also be introduced at the top of the furnace with the charges, but the use of alkalies for seizing the sulphur of the coke forms no part of my invention."

Mr. Parry's process appears to me to be founded on correct principles; but its adoption must depend on the cost of production relatively to the market value of the quality of iron which it yields. It has been carefully tested by actual practice at the Ebbw Vale Ironworks, and not less than 80 tons of metal have been made by it. Bar-iron, practically free from sulphur and phosphorus, might successfully compete with Swedish or Russian iron for the manufacture of steel, and would be cheap at considerably more than 8*l.* per ton.

The brown smoke, which Mr. Parry describes, deserves particular

attention. I have minutely interrogated him on the subject, and am satisfied of the entire accuracy of his statement regarding it. It is a very singular and interesting fact. It may be seen at a great distance, and in a furnace 3 ft. high there was a loss of 4 cwts. to the ton by the sublimation of oxide of iron. The late Mr. Joseph Hall, of whom hereafter particular mention will be made, previously announced that great loss of iron might occur from vaporization "at a very high temperature;" and he records one instance in which, "after placing 4 cwts. of iron in the furnace, it was found, on finishing the process, that only 1 cwt. remained, the other 3 cwts., excepting the scoria, having escaped in the shape of vapour or gas."[4] There may have been a mistake in the observations, nevertheless the announcement deserves to be mentioned.

Mr. Parry has communicated to me some singular results, which should be recorded in this place. He has proposed, what he designates, a steam-refinery, which is in successful operation at the Ebbw Vale Iron-works. It is simply a reverberatory furnace having a very high fire-bridge, so that the flame seems to come down from the roof, and play directly upon the molten metal underneath. It is built in front of a blast-furnace, from which about 35 cwts. of pig-iron are run into it at a time. There are 2 air-twyers, 1⅛ in. diameter each, and 1 water-twyer, 1½ in. diameter, from the centre of which a jet of superheated steam, ⅛ in. diameter, escapes, carrying with it into the furnace by the induced current a large quantity of atmospheric air. The effect of the steam is to remove some sulphur from the pig-iron; but its effect in removing phosphorus and sulphur from the cinder is reported to be ten times greater, the cinder subsequently tapped out being as free from these ingredients as most iron-ores. But when the cinder is "steamed" alone, the effect is comparatively feeble. The consumption of coal is 2 cwts. to the ton of refined metal; whereas in the old refinery 6 cwts. of coke are consumed for the same quantity of refined metal, besides that required to produce blast for 6 twyers. It will be specially noted that a subjacent stratum of molten pig-iron is stated to be essential to the dephosphurization and desulphurization of the cinder. Mr. Parry supposes that both phosphorus and sulphur escape as phosphuretted and sulphuretted hydrogen respectively; and if this be so, the hydrogen developed by the action of the steam upon the molten metal may play an important part in these actions.

It deserves to be mentioned that, many years previously, Guenyveau recommended a mixture of atmospheric air and steam as a powerful means of oxidation, when projected upon molten pig-iron in a puddling-furnace.[5]

Manganese, being more oxidizable than iron, is readily separated in the operation of puddling, and passes into the cinder, combining with silica to form silicate of protoxide.

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[4] The Iron Question, p. 42.

[5] Nouveaux Procédés pour fabriquer la Fonte et le Fer en Barres. Par A. Guenyveau, Ingénieur en chef et professeur de Minéralurgie à l'École Royale des Mines de France. Paris, 1835, 8vo. p. 63.

With respect to the minute proportions of aluminium, calcium, magnesium, etc., occasionally present in pig-iron, it is easy to understand how they should more or less completely be removed by oxidation, either by the direct action of the oxygen of the air, or by that of the oxygen on the oxidized compounds of iron in the bed of the furnace.

ANALYSES OF TAP-CINDER.

	I.	II.	III.	IV.	V.	VI.
Silica	7·71	8·32	11·76	29·60	23·86	15·30
Protoxide of iron	66·32	57·67	58·67	48·43	39·83	60·14
Sesquioxide of iron	8·27	13·53	17·00	17·11	23·75	16·42
Protoxide of manganese	1·29	0·78	0·57	1·13	6·17	2·29
Alumina	1·63	1·88	2·84	1·28	0·91	traces
Lime	3·91	4·70	2·88	0·47	0·28	0·70
Magnesia	0·34	0·26	0·29	0·35	0·24	0·42
Sulphide of iron (FeS)	..	7·07	3·11	1·61	0·62	..
Sulphur	1·78	..	..	..	..	traces
Phosphoric acid	8·07	7·29	4·27	1·34	6·42	4·66
Copper	traces	traces	..	..	..	..
	99·32	101·50	101·39	101·32	102·08	99·93
Metallic iron °/₀	57·37	58·04	..	44·22	47·60	58·26

I. By Mr. E. Riley, at the Dowlais Iron-works. It was produced in "boiling" common white pig-iron alone, for the middle of rails. II. Also by Mr. Riley. Described simply as "forge-cinder," produced in a furnace working with limestone boshes, *i. e.* the sides of the bed lined with limestone. Both these cinders appear to be mixtures of tribasic silicate of protoxide with magnetic oxide of iron.

III. By Mr. Riley. The cinder was produced at Dowlais in a furnace working with boshes of red ore, and from 50 lbs. to 60 lbs. of red ore were thrown in at every heat. The quality of the pig-iron operated upon in forming both this and the cinder in No. II. was very bad, having been made with large quantities of cinder and blackband, of bad quality. The iron was rotten under the rolls, and by the use of red ore in the puddling-furnace this defect was to a certain extent remedied. The proportion of sulphur was less than half that in the cinder of No. II.; and Mr. Riley suggests that that element may be partially oxidized by the red ore.

IV. By the Author. The specimen was in distinct, beautiful, bright, black crystals, of iron chrysolite or olivine, belonging to the prismatic system. Their hardness was equal to 6, and their specific gravity at 18°6 C. 4·0805.[6] It was found by Mr. John Dawes in the flue of a puddling-furnace at the Bromford Iron-works, where it had probably been exposed to a high temperature for a considerable time. I have previously referred to this slag, of which, estimating the whole of the iron as protoxide, the formula closely approximates to $3FeO, SiO^3$. The presence of sesquioxide of iron has also been considered, and is easily explained by the fact that this silicate absorbs oxygen at a

[6] Rep. on Crystalline Slags, *ante cit.*

high temperature. V. By the Author. This specimen was found by Mr. C. Twamley, in a heap of "bull-dog," at the Bloomfield Iron-works, Tipton, Staffordshire. It was in large iron-grey crystals, too dull for admeasurement by the reflective goniometer; but they were sufficiently distinct to leave no doubt as to the fact of their being identical in form with No. IV. The specific gravity, at 18°2 C., was 4·1885. It strongly attracted the magnetic needle. I have previously considered the composition of this slag, which is certainly to be regarded as pseudomorphous. It was originally tribasic silicate of protoxide of iron, which has been in part converted into sesquioxide during the process of calcining tap-cinder to be used as "bull-dog." VI. Analyst not known. I received the analysis many years ago from the late Mr. Barker, of the Chillington Iron-works, near Wolverhampton. The cinder appears to be a mixture of tribasic silicate of protoxide with magnetic oxide of iron.

With reference to the use of limestone for protecting the sides of the bed of the puddling-furnace, Mr. John Gibbons, an experienced smelter and manufacturer of iron in South Staffordshire, has published the following observations:—"I know that it has been frequently tried, and as frequently abandoned by many, under the idea of its causing unsoundness in the iron; and unless most carefully used it has certainly this tendency. I have, therefore (particularly when making best iron), been in the habit of mixing with it, or substituting for it, the red Newcastle mine [North Staffordshire 'red mine:' see Table of the Composition of Iron-Ores] and burnt *tap*-cinder ['bull-dog'], the limestone about the bridge and the hotter parts of the furnace, the other materials either partially or altogether elsewhere. The limestone resists the fire best, and I have a notion that it contributes to the toughness of the iron; it has the effect, too, of considerably improving the yield; why, I cannot imagine, but so it is,—still the other materials are safer to use."[7]

According to Mr. Arkinstall's experience, iron puddled with limestone fettling is always rotten and red-short, being often completely spoiled. He states that by its use a thick cinder is formed, and the iron is certainly not toughened.

I was informed at the Cyfartha Works that limestone boshes had been tried in the puddling-furnaces there, and with the effect of making the iron very red-short. Iron bottoms were used with sides of firebrick, fettled with clay. Neither "bull-dog" nor red ore was employed (1859).

At Pontypool, iron bottoms made of boiler-plate scrap were used; and the sides were of firebrick, fettled with a mixture of "foxtail" (*i. e.* cinder from the charcoal finery) and sandstone (1859).

Invention of the boiling process.—"Pig-boiling" is the expression usually applied to this process. It consists essentially, as we have seen, in the decarburization of the pig-iron by contact with oxidized com-

[7] Practical Remarks on the Use of the Cinder Pig in the Puddling Furnace; and on the Management of the Forge and Mill. London, 8vo. 1844, p. 21.

pounds of iron, whereby carbonic oxide is produced below the surface of the molten metal, and in escaping causes the *appearance* of ebullition or "boiling." The phenomenon, it need hardly be observed, is not actual ebullition, but simply effervescence, resembling that due to the evolution of carbonic acid from soda-water. In this process, the bed of the furnace, in which fusion of the pig-iron takes place, is coated with solid oxidized compounds of iron, and there is also a stratum of liquid cinder, of which the chief constituent is protoxide of iron. Hence, this process of puddling is termed "wet," in contradistinction to the old method of working on sand-bottoms, which is termed "dry" from the absence of such a bath of cinder. The merit of introducing "wet" puddling or "pig-boiling" is ascribed, and, as I believe, with reason, to the late Mr. Joseph Hall, of the Bloomfield Iron-works, Tipton, Staffordshire; but that merit has been disputed, and in this respect Mr. Hall has only met with the fate which seems especially to have befallen the authors of every other improvement of importance in the smelting and manufacture of iron. Mr. Hall, whom I knew personally, was, undoubtedly, one of the most experienced and skilful producers of wrought-iron in South Staffordshire; and no firm in that county has enjoyed a higher reputation for the quality of its manufactured iron, for example, boiler-plates, than Bradley, Barrows, and Hall. Mr. Hall died in 1862, having attained the age of 72; and five years previously he published a little volume, in which he asserted his claim as the inventor of "pig-boiling" and other improvements connected with puddling, in a manner as ostentatious as it was injudicious.[*] He was essentially the practical man; and, as is usual with men of that class, he displayed much ignorance of the science of his art, and not a little inclination to dogmatize. It is to be regretted that Mr. Hall ever appeared before the world in the capacity of author.

Mr. Hall sought to establish his reputation as an inventor on three grounds:—first, "the substitution of cinder for sand upon the plates for the puddling-furnace bottoms," to which he was accidentally led by attempts to save and work up the residue, rich in iron, of forges, such as "the contents of puddlers' boshes;" secondly, an improved construction of iron bottoms, consisting of "a frame of plates, united one to another, all round the inside of the furnace, of a height of about 15 in. or 16 in., with a projection of fire-brick hanging over the top of the plates," an idea which, he informs us, "was the result of years of brain-work," and of "incessant thought by night and by day;" and, thirdly, the application of roasted tap-cinder or "bull-dog." He further declares, that neither for "the *pig-boiling* principle with its *furnace*," which, if they had been secured by patent, he believes "would have realized by this time [1857] perhaps a million of money," nor for the invention of "bull-dog," which was patented, did he receive any

[*] The Iron Question: considered in connection with Theory, Practice, and Experience, with special reference to "The Bessemer Process." By Joseph Hall. London, 1857, 8vo. pp. 73.

compensation from other persons engaged in the same trade as himself. "On naming the project [of the improved furnace bottom] to a practical man, he laughed at it, and pronounced the attempt as impossible, as it appeared on the first blush ridiculous." Mr. Hall asserts, that "of all the principles introduced since the days of Tubal Cain, that of 'dry pig-puddling' on the sand bottom is the worst;" and he is strong in his praise of Homfray, who is reputed to have introduced the process of refining.

As far as I have been able to ascertain the truth, I believe that Mr. Hall was fairly entitled to much of the credit which he claimed for himself.

Mr. Arkinstall informs me that the late Mr. John Dawes made experiments on this subject with the same results as Mr. Hall, and that he has seen specimens of puddled bars which were produced by Mr. Dawes in his trials.

With respect to the alleged invention of "bull-dog" by Mr. Hall, the late Mr. John Gibbons published the following statement:—"Recently a patent has been taken out for an elaborate mode of burning tap-cinder in kilns. I can readily believe that its quality, or power of resisting heat, may be improved thereby; but I have not thought it necessary to alter my old method of burning it in open heaps, just like ironstone. In this way, mixed with the other materials, or alone, it will be found to do very well."[9] Burning in kilns, however, is admitted to have been an improvement.

I have previously explained the change which is effected by roasting the cinder, and that change is the same whether the roasting takes place in kilns or in open heaps, so that Mr. Hall's claim as the inventor of "bull dog" may be reasonably questioned. Mr. Gibbons's method is still practised in some localities.

Double Puddling-Furnaces.

The bed of these furnaces is twice as large as that of an ordinary puddling-furnace, and there is a working door on each side, one exactly opposite the other. A large charge is introduced, and two puddlers work simultaneously, one at each door. Furnaces of this kind are, I believe, in use at the Pentwrch Works in South Wales, but I have never seen them in operation. It is obviously essential that the puddlers, who thus work together, should be equally skilful and on the best terms with each other; for, otherwise, quarrels might naturally be expected to arise in the event of bad workmanship.

Mechanical Puddling.

Many schemes have been proposed and patented to effect the work of the puddler by machinery, but hitherto, I believe, without complete

[9] Practical Remarks, p. 71.

success. And certainly no method of the kind has yet been adopted in our forges. The furnace bottoms have been made to rotate; the molten metal has been stirred about by means of revolving vertical shafts with arms attached at right angles, etc. Our ironmasters would only be too glad to dispense with the manipulation of puddlers, with whom so many difficulties have from time to time arisen. Tooth's patent for puddling by a self-acting machine[1] was exhibited at work in London—not the most suitable locality for such an exhibition. The proprietors of the patent, Messrs. W. H. Tooth and W. Yates, jun., issued circulars dated February, 1861, inviting inspection of the process in operation at 21, Rhodeswell Road, Stepney, asserting that the problem of puddling by machinery had at length been successfully solved. Mr. Yates informed me by letter (dated from the Mersey Steel and Iron Company's Office, in London, March 1, 1861), that there was "one remarkable fact" in their method, which to him appeared "inexplicable," namely, that the balls produced weighed more than the materials introduced into the charge. In one instance the charge consisted of 3 cwts. of pig-iron and 28 lbs. of hammer-scale, making a total of 3 cwts. 1 qr.; and the balls drawn out weighed 3 cwts. 2 qrs. 8 lbs., or 36 lbs. in excess. I confess that to me also the result is inexplicable. I present the statement as I received it, and must leave ironmasters to form their own judgment respecting it.

Mr. James Nasmyth, of Hammer celebrity, has patented a method of puddling, in which a current or currents of steam are "introduced as nearly as practicable to the lowest portion of the molten iron, and thence diffused upwards, so as not only mechanically to agitate the molten iron, and thereby keep exposing fresh surfaces of the iron to the oxygen contained in the atmosphere passing through the furnace, but also, when brought in contact with the incandescent iron, to be reduced to its elements and yield oxygen." The oxygen, it is alleged, combines with the carbon, and also with the sulphur and other oxidizable substances in the iron, and removes them. "For a charge of 392 lbs. of Scotch, 203 of pig-iron, and 88 lbs. of white Staffordshire pig-iron, the introduction of steam, shortly after the iron is melted, for from two to five minutes, is attended with very beneficial results."[2] After what has been advanced concerning the application of steam in Mr. Parry's so-called steam-refinery, nothing need be said with reference to Mr. Nasmyth's process, except that the decomposition of steam by molten pig-iron must necessarily occasion great reduction of temperature.

After the descriptions given of hot-blast ovens and puddling-furnaces, the construction will be clearly intelligible from the engravings. The hot-blast apparatus, it will be observed, is suspended on side-brackets (vid. p. 673).

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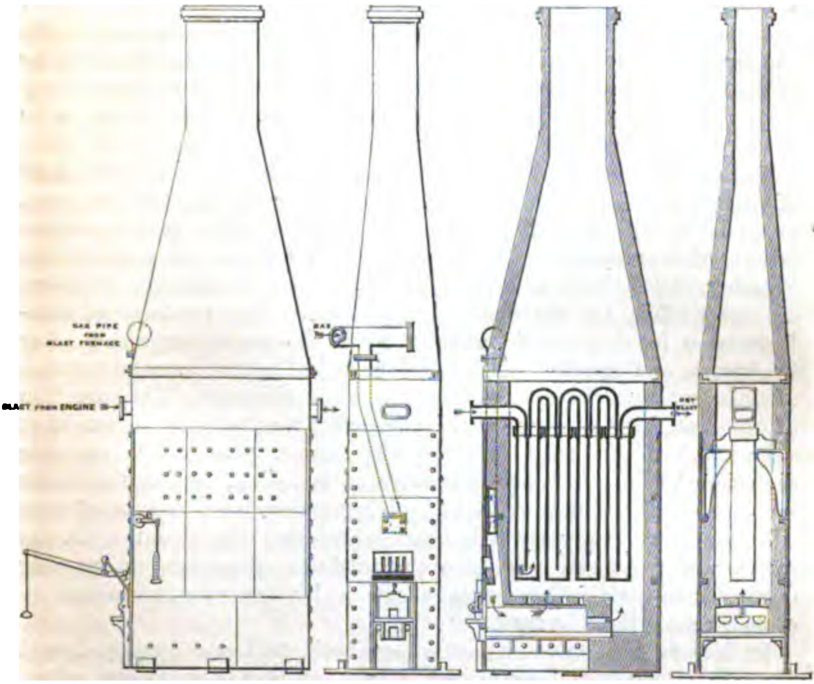
[1] A.D. 1860. No. 277.
[2] Abridgments, etc. *ante cit.* p. 171. A.D. 1854, May 4th. No. 1001.

Application of Waste Blast-furnace Gas to Puddling.

A few years ago Mr. Levick erected a puddling furnace at the Coalbrook Vale Works at Cwm Celyn, with a view to the application of the waste blast-furnace gas as the source of heat; and further to apply the heated products of combustion escaping from this puddling furnace to a hot-blast oven. The arrangement devised and carried into practice is shown in the accompanying engravings, executed from



1. 2 3. 4.

Fig. 161. 1. Mr. Levick's gas puddling furnace, side elevation.—2. End elevation at the fire-place.—3. Longitudinal section on the median line.—4. Transverse section.

drawings for which I am indebted to Mr. Levick. I examined the furnace in 1859, when it was not at work; but I saw balls which had been made in it, and which proved that a sufficiently high temperature for puddling had been attained. It was only to be regarded as an experimental furnace, and its operation was not a complete success.

Siemens's Gas Puddling Furnace.[1]

I am indebted to Mr. Frederick Siemens for the drawings from which the accompanying engravings have been executed, and for the follow-

[1] Patented A.D. 1856, Dec. 2. No. 2861. "Improved arrangements of furnaces, which improvements are applicable in all cases where great heat is required."

ing description drawn up by my former pupil Mr. Hackney, now in Messrs. Siemens's employ. Although somewhat out of place in this volume, yet I have inserted the description of a new method of working devised and successfully carried into practice by Mr. Siemens at Wednesbury near Birmingham, and which I did not receive in time for publication in the First Part. The puddling furnace described is at the Earl of Dudley's Iron-works near Dudley. An explosion occurred, and for a season stopped the working of the furnace: but I am informed by Mr. Richard Smith, the Earl of Dudley's agent, that this new method of heating the furnace is every way successful. In the first application of an invention difficulties are naturally to be expected. I anticipate results of great importance in Metallurgy from the extension of Siemens's furnace, which appears to me to be founded on truly philosophical principles.

The principle of these furnaces is the transfer of the waste heat of the products of combustion either to the air or combustible gases, or to both, which enter the furnace. This transfer is effected by means of "regenerators,"[1] each of which consists of a brickwork chamber, filled with a mass of loosely piled fire-bricks, exposing a large surface for the absorption of heat. The products of combustion on leaving the furnace are made to pass through this loose brickwork, and are thus gradually deprived of a very large proportion of their heat, previous to escaping into the chimney. The direction of the draught is now reversed by means of a suitable arrangement of valves, when the gases entering the furnace pass in the opposite direction through the heated regenerators, encountering first the cooler portions of the brickwork, and acquiring successive additions of heat till they issue at a very high temperature into the chamber, *i.e.* the interior, of the furnace, whence the products of combustion, passing down through the other regenerators, which are now comparatively cooled, reheat them in turn.

In Messrs. Siemens's earlier furnaces solid fuel was employed, and the air required for combustion was thus heated by means of regenerators. In one form of these early regenerative furnaces, which has been uninterruptedly at work during several years, for heating bars of steel, at Messrs. Marriott and Atkinson's Steel-works, Sheffield, and also at the Broughton Copper-works, Manchester, there is a single fire-place, containing a ridge of fuel fed from the top, and two heating chambers, in which the bars of metal to be heated are laid, with a regenerator at the end of each chamber, whereby the waste heat passing off to the chimney is intercepted; and on reversing the draught by means of a valve, the air entering the furnace is made to pass through the heated regenerator in the contrary direction, and issuing at a very high temperature into the first chamber of the furnace, it traverses the ridge of fuel and produces a flame which fills the second heating chamber, whence the products of combustion passing through the second regenerator, deposit their heat successively in the inverse

[1] A better and more correct term would be "accumulators."

manner, reaching the chimney comparatively cool. By thus alternating the current through the two regenerators, a high temperature is maintained constantly in the furnace. This arrangement of furnace is evidently applicable only in exceptional cases, where two chambers are to be heated alternately, and it does not admit of being carried out on a large scale.

In attempting to apply the principle to heating a *single chamber*, as in puddling and other larger furnaces, serious practical difficulties arose, which for a considerable time frustrated all efforts, until, by adopting the plan of converting the solid into gaseous fuel in the first instance, and employing it entirely in the gaseous form for heating purposes, practical results were at length attained, surpassing expectations.

When a uniform and sufficient supply of combustible gas is ensured, it can evidently be heated just like the air, by being passed through a separate regenerator before reaching the furnace, whereby its heating power is greatly increased. The difficulty of maintaining a uniform flame in the furnace is thereby certainly removed, and there is no longer any necessity for keeping the flame always in the same direction through the furnace, since the gas can be introduced with equal facility at each end of the heating chamber in turn, and the periodical change of direction of the flame through the furnace tends only to make the temperature more uniform throughout; whereas in the previous plan of employing solid fuel for heating in the furnace, the relative position of the fireplace and heating chamber being fixed and unchangeable, required the direction of the flame to be kept always the same, unaltered by the reversal of currents through the regenerators. The plan of a separate gas-producer has now been successfully carried out in practice, and many regenerative gas furnaces are already in satisfactory operation in this country and on the Continent; applied to the manufacture of glass and zinc, to puddling, gas making, the welding of iron tubes, the melting of steel and Muntz's metal, etc.

The regenerators may be underneath or at the side of the furnace, but it is of importance that they should always be placed at a lower level than the heating chamber, in order that the heated air and gas may rise naturally into it, forming there a plenum of pressure. The products of combustion are drawn down through the other comparatively cool pair of regenerators by the chimney draught, which is regulated by a damper.

The gas producers are entirely separate from the furnaces, where the heat is required, and are made sufficient in number and capacity to supply several furnaces from a common gas flue.

Two forms of gas producer are now in use; the first or ordinary producer is shown in figs. 162 and 163; fig. 162 is a longitudinal section of the producer, fig. 163 a plan of a set of three producers. The fuel, which may be of the poorest description, such as slack, coke-dust, lignite, or peat, is supplied at intervals of from 6 to 8 hours through the covered holes (a, a), and descends gradually on the inclined plane (b), which is set at an inclination of from 45° to 60°,

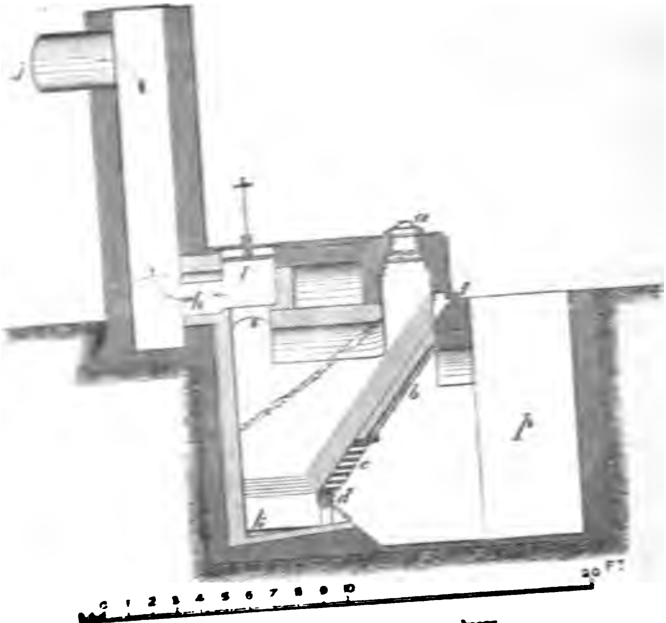


Fig. 162. Longitudinal section of gas-producer.

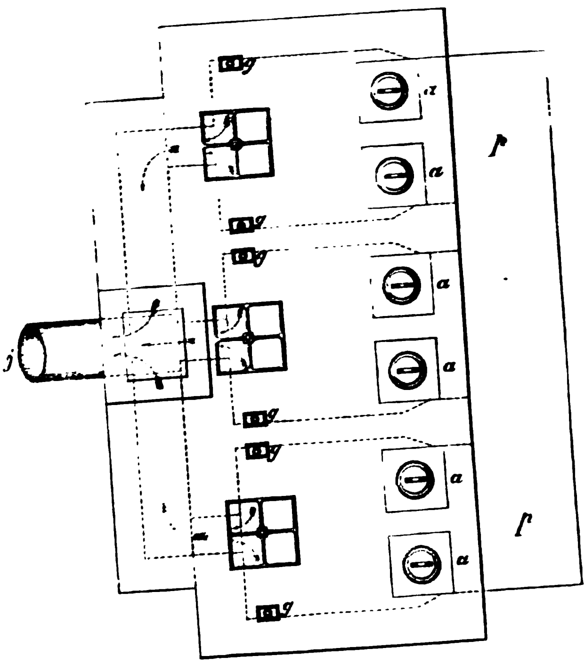


Fig. 163. Plan of a set of three producers.

according to the nature of the fuel used. The upper portion of the incline (*b*) is made solid, being formed of iron plates covered with fire-brick, but the lower portion (*c*) is an open grate formed of horizontal flat steps. At the foot of the grate (*c*) there is generally a covered water-trough (*d*), filled by a supply pipe (not shown in the drawing) which opens by a funnel placed below a water tap in the pit (*p*): but in many producers, instead of a water-trough, or in addition to it, water is simply run into the bottom of the producer, the floor of which is sloped back for the purpose, as shown at (*k*), and has a thin iron-plate built into the brick-work to prevent leakage. The large opening under the water-trough is convenient for drawing out clinkers, which generally collect at that point. The small stoppered holes (*f*), fig. 162, at the front (of which there are three in each producer), and (*g*, *g*), fig. 163, at the top, are provided to allow of putting in an iron bar occasionally to break up the mass of fuel and detach clinkers from the side-walls. Below the grate the producer is 6 feet wide inside; above the grate it widens out to 7 feet. Each producer is made large enough to hold 10 or 12 tons of fuel in a low incandescent state, and is capable of converting about 2 tons of it daily into a combustible gas, which passes off through the opening (*h*) into the main gas flue leading to the furnaces.

The action of the gas producer in working is as follows: the fuel descending slowly on the solid portion (*b*) of the inclined plane, fig. 162, becomes heated and parts with its volatile constituents,—the hydrocarbon gases, water, ammonia, and some carbonic acid,—which are the same as would be evolved from it in a gas retort. There now remains from 60°/$_{0}$ to 70°/$_{0}$ of purely carbonaceous matter to be disposed of, which is accomplished by the slow current of air entering through the grate (*c*), which produces regular combustion immediately upon the grate; but the carbonic acid formed, having to pass slowly on through a layer of incandescent fuel from 3 to 4 feet thick, takes up another equivalent of carbon, and the resulting carbonic oxide passes off with the other combustible gases to the furnace. For every cubic foot of combustible carbonic oxide thus produced, 2 cubic feet of incombustible nitrogen pass also through the grate, tending greatly to diminish the richness or heating power of the gas. But not all the carbonaceous portion of the fuel is volatilised on such disadvantageous terms; for the water trough (*d*) at the foot of the grate, absorbing the spare heat from the fire, emits steam through a row of small holes under the lid; and each cubic foot of steam in traversing the layer of from 3 to 4 feet of incandescent fuel is decomposed into a mixture consisting of 1 cubic foot of hydrogen and nearly an equal volume of carbonic oxide, with a variable small proportion of carbonic acid. Thus 1 cubic foot of steam yields as much inflammable gas as 5 cubic feet of atmospheric air; but the one operation is dependent upon the other, inasmuch as the passage of air through the fire is attended with the evolution of heat, whereas the production of the water gases (as well as the evolution of the hydrocarbons) is carried on at the expense of heat.

The generation of steam, being dependent on the amount of heat in

the fire, regulates itself naturally to the requirements; and the total production of combustible gases varies with the admission of air. And since the admission of air into the grate depends in its turn upon the withdrawal of the gases evolved in the producer, the production of the gases is entirely regulated by the demand for them. The production of gas may even be arrested entirely for 12 hours without damaging the producer, which will begin work again as soon as the gas valve of the furnace is reopened; since the mass of fuel and brickwork retains sufficient heat to keep up a dull red heat in the producer during that interval. The gas, however, is of a more uniform quality when there is a continuous demand for it, and for this reason [as well as that any one furnace, whenever it is necessary for a particular stage of its work, may be supplied with an amount of gas far above its *ordinary* requirements] it is best to supply several furnaces from one set of producers, and to keep the producers constantly at work. The opening (*h*) leading from each producer into the main gas flue can be closed by a valve (*i*), as shown in fig. 162, in case any one of the producers is required to be stopped for repairs, or because part of the furnaces supplied are out of work.

The second form of gas producer, the regenerative gas and coke oven, is intended, like Davis's breeze-oven, to burn the non-caking Thick-coal slack of Staffordshire, producing a hard brilliant "breeze," well adapted for smiths' fires, and economising the heat and gas generated. It is superior to Davis's breeze-oven in working *continuously*, and in effecting a much greater saving of heat. The construction of

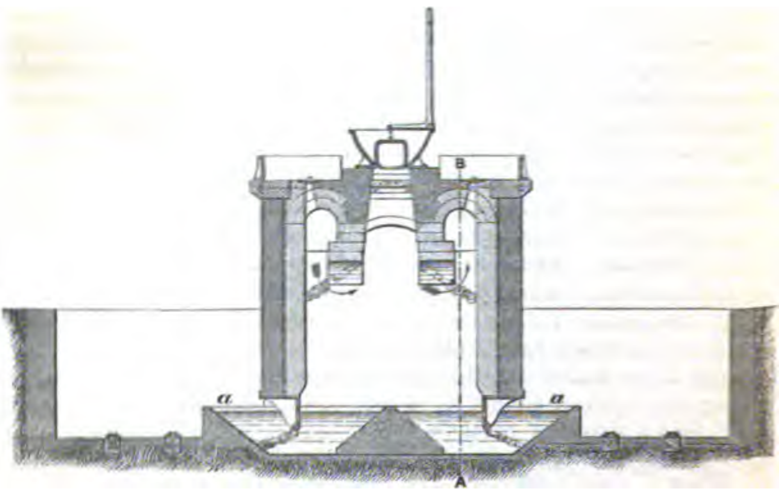


Fig. 164. Second form of Siemens's gas-producer. Transverse section through the chamber on line C D E F, fig. 166.

the oven is shown in figs. 164 to 167; it consists of a chamber lined with fire-brick, the upper part of which is divided into three segments by two flat arches running longitudinally from end to end: at one end of the chamber are two regenerators, which communicate with the

above lateral spaces. Fig 166 is a longitudinal section of the oven; fig. 164 a transverse section through the chamber; fig. 165 a transverse section through the two regenerators; and fig. 167 a transverse section through the reversing valve.

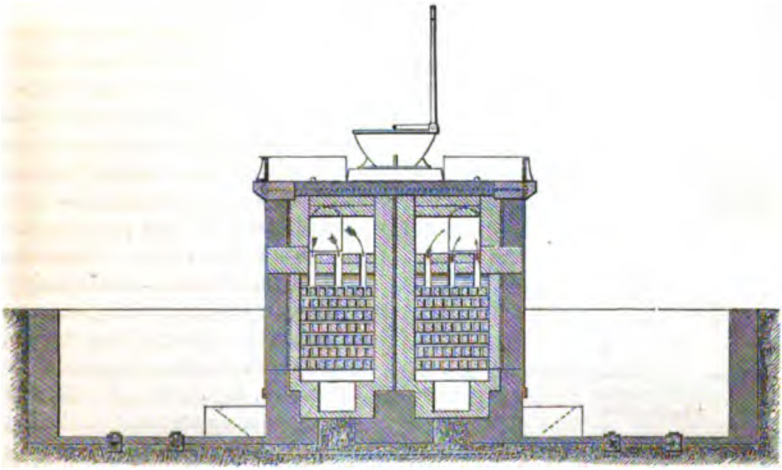


Fig. 165. Second form of Siemens's gas-producer. Transverse section through the two regenerators on line G H, fig. 166.

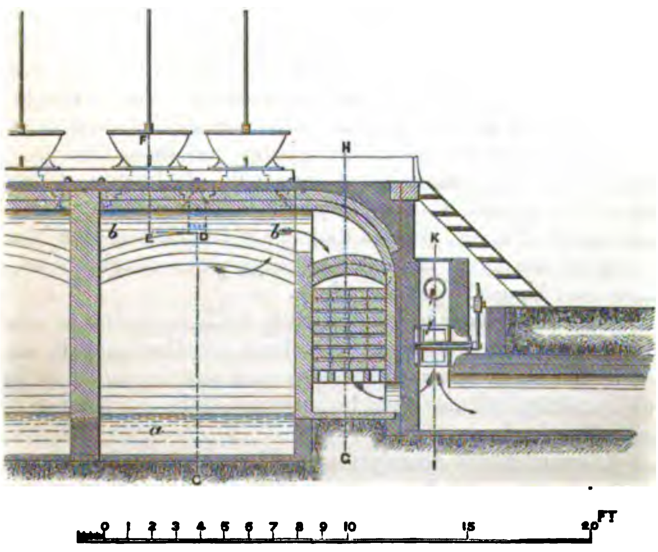


Fig. 166. Second form of Siemens's gas-producer. Longitudinal section on line A B, fig. 164.

The side walls of the oven are supported below by strong cast-iron bearers, the lower edges of which dip into a trough of water (*a*, *a*), lined with sheet-iron to prevent leakage. The walls of the oven are for the most part built double, as shown in figs. 164 and 165, with

a layer of sand in the middle to assist in retaining the heat, and to prevent the escape of gas by filling up any cracks in the brickwork.

The fuel is supplied at intervals through the two cast-iron hoppers at the top, and fills the whole chamber with the exception of the two side spaces [illegible], fig. 166. It is burnt by a current of air, which, entering through the tube [illegible], figs. 166 and 167, passes in the direction shown by the arrows, up through one regenerator and across under the two longitudinal arches *through the mass of fuel in the oven*: the gas produced passes down through the other regenerator, depositing successively the greater part of its heat, and thence escapes in a cooled state into the gas flue (as shown in fig. 167). When the second regenerator is sufficiently heated by the descending current of gas, the direction of the draught through the oven is reversed by the valve, figs. 166 and 167, and the air passing up through the hot regenerator enters the oven at a high temperature, while the current of gas passes down through the first regenerator and reheats it. The air is forced into the oven by a steam-jet shown in fig. 167: this method of producing the blast has the advantages of increasing the production of gas by the action of the steam on the red-hot fuel, and of returning *more heat* to the oven; for the air which is required to support combustion is not by itself sufficient in quantity to take up all the heat which the gas loses in passing through the regenerator. The "breeze" produced is raked out at intervals at each side of the oven from under the cast-iron bearers, more coal-slack being put in at the top. There are three small stoppered holes at each side of the top of the oven, through which an iron bar may be put to stir or break up the mass of fuel, and a row of holes, about a foot apart, in the cast-iron bearers at the bottom of the oven, to allow any large piece of coke to be broken up if it cannot be easily got out whole.

Fig. 167. Second form of Siemens's gas-producer. Section through the reversing valve on line I K, fig. 166.

These coke-ovens may be conveniently built in pairs, as shown in fig. 166, and a number of such pairs built together may be arranged in *rows*, with a small tramway between each row (as shown in figs. 164 and 165), and fig. 166 may then be supposed to be a section of an oven *at the end* of such a row.

A single oven of this description has been in use for some time at Messrs. James Russel and Sons' Crown Tube-works, Wednesbury, and a second is now being built. One such oven is found to produce, besides breeze, as much gas as *five or six* ordinary producers.

It is important that the main gas-flue leading to the furnaces should contain an excess of pressure, however slight, above the atmosphere, in order to prevent any inward draughts of air through crevices, which would produce a partial combustion of the gas and diminish its heating power in the furnace, besides causing a deposit of soot in

the flues. It is therefore necessary to deliver the gas into the furnace, without depending upon a chimney-draught for that purpose. In the gas and coke oven this is done by means of the *blast*, and in the case of the ordinary gas producers it could easily be accomplished if the producers were placed at a lower level than the furnaces; but, as that is generally impossible, the following plan has been adopted. The mixture of gases on leaving the producers has a temperature ranging between 300° and 400° Fahr., and this initial heat is made available for producing a plenum of pressure, by making the gas rise about 20 ft. above the producers, then carrying it horizontally 20 ft. or 30 ft. through the wrought-iron tube (*j*), figs. 162 and 163, and letting it again descend to the furnace. The horizontal tube (*j*), being exposed to the atmosphere, causes the gas to lose from 100° to 150° of temperature, which increases its density from 15% to 20%, and gives a preponderating weight to that extent to the descending column, urging it forward into the furnace.

The gases proceeding from the gas producers are a mixture of olefiant gas, marsh gas, hydrogen, carbonic oxide, vapour of tar, water, and ammoniacal compounds; besides nitrogen, carbonic acid, some sulphuretted hydrogen, and some bisulphide of carbon. The specific gravity of this mixture averages 0·78, that of air being 1·00; and a ton of fuel, not including the earthy matter, produces, according to calculation, nearly 64,000 cubic feet of gas. By heating these gases to 3000° F. their volume would be fully six times increased, but in reality a much larger increase of volume ensues, in consequence of some important chemical changes effected at the same time. The olefiant gas and tar vapour are well known to deposit carbon on being heated to redness, which is immediately taken up by the carbonic acid and vapour of water, the former being converted into carbonic oxide, and the latter into carbonic oxide with some carbonic acid and pure hydrogen. The ammoniacal gas and sulphuretted hydrogen are also resolved into permanently elastic gases, with a preponderance of hydrogen. These chemical changes represent a large absorption of heat from the regenerator, but the heat is given out again by combustion in the furnace, enhancing the heating power of the fuel beyond the increase due to elevation of temperature alone: it is also of importance in preventing "sulphuring"; for it is believed that the sulphur in separating from its hydrogen takes up oxygen supplied by the carbonic acid and water, forming sulphurous acid, a stable compound, which is not decomposed on meeting with metallic oxides in the furnace. This view is so far borne out by experience, that glass containing a moderate proportion of lead in its composition may be melted in open pots without injury, instead of requiring covered pots, as in ordinary furnaces heated directly by coal.

As an example of the general mode of construction of these furnaces, the application of the system to *puddling* has been selected for detailed description.

The regenerative gas puddling-furnace is shown in figs. 168 to 173*a*.

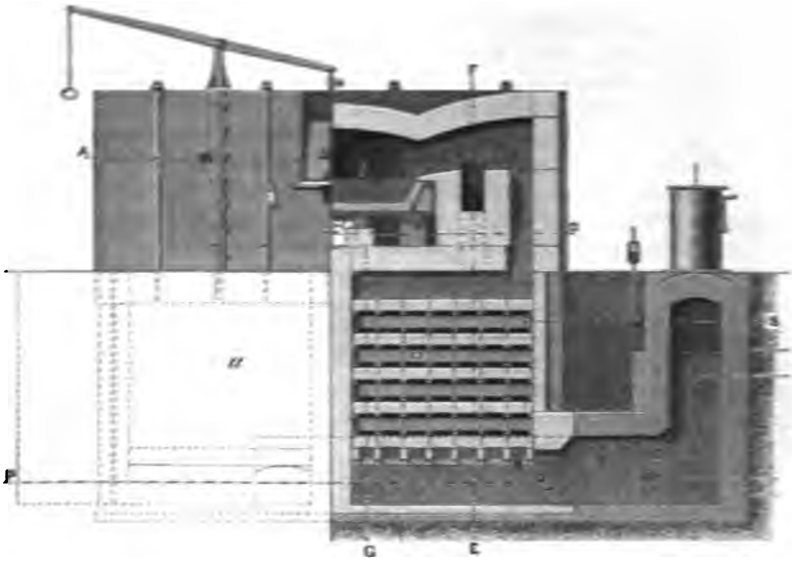


Fig. 168. Regenerative gas puddling furnace. Half front elevation and half vertical section on line I K, fig. 171.

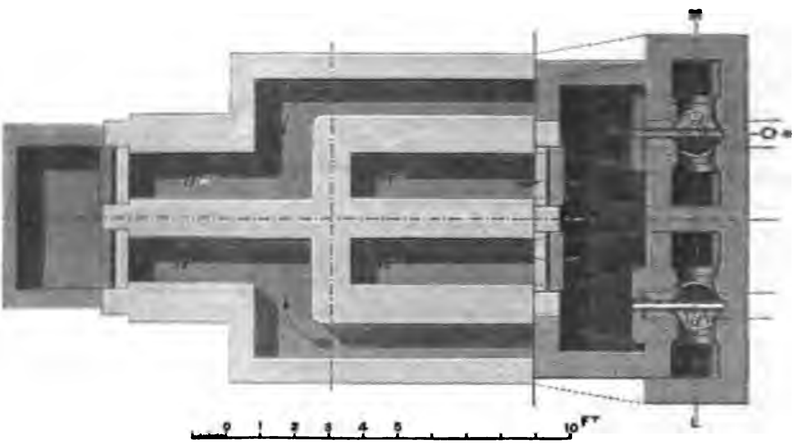


Fig. 169. Horizontal section on line P Q R S, fig. 168.

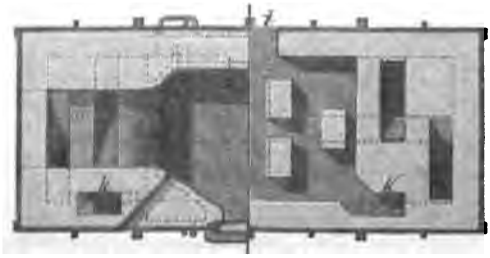


Fig. 170. Horizontal section on line A B C D, fig. 168.

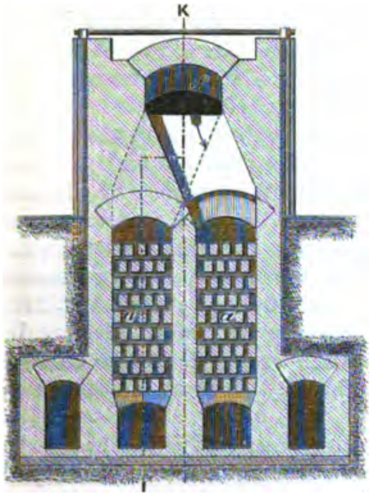


Fig. 171. Vertical section on line E F, fig. 168.

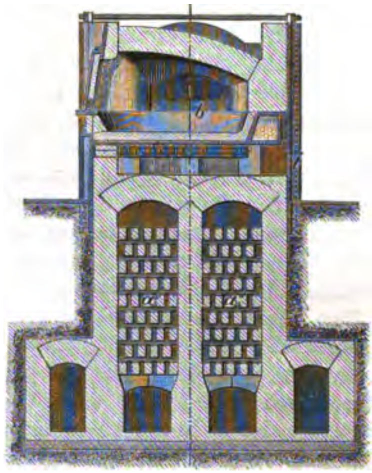


Fig. 172. Vertical section on line G H, fig. 168.

The four regenerators, a, a', a'', a''', are in this case arranged longitudinally underneath the puddling-chamber, b, which may be of the usual form. The regenerators work in pairs, the two under the right-hand end of the bed communicating with that end of the puddling-chamber, while the other two communicate with the opposite end, as shown in fig. 171. The two regenerators next the *front* of the furnace may be called the *gas regenerators*, as they serve to heat the gas on its way to the puddling-chamber, and communicate by flues, c, c', fig. 173*a*, with the gas valve, d, and the pipe from the gas producers, e; the other two regenerators are *air regenerators.*

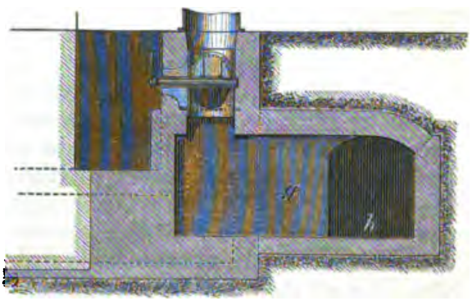


Fig. 173. Vertical section on line N O, fig. 169.

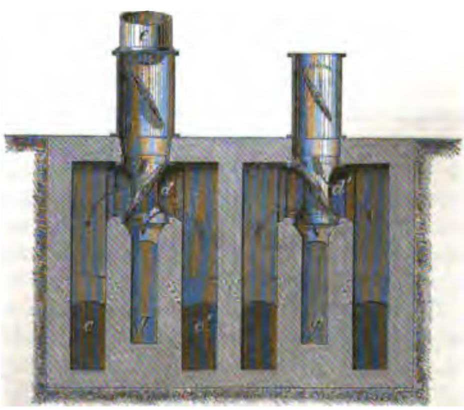


Fig. 173*a*. Section on line L M, fig. 169.

When the valves, d, d', are in the position shown in the engravings, the gas from the producers is directed by the gas-reversing valve, as indicated by the arrows (figs. 169, 171),

into the left-hand gas regenerator, and rising through the heated brickwork, flows in a transverse sheet into the mixing chamber, f, at that end of the furnace; at the same time the air required for the combustion is directed by the air valve, d (figs. 168, 173), into the left-hand air regenerator, and rising through it, enters the mixing chamber beyond the gas; and therefore when the air and gas pass forward together into the puddling-chamber, the air is above the gas, and tending, from its greater specific gravity, to sink through it, produces a perfect mixture. The products of combustion pass down through the right-hand pair of regenerators, as indicated by the arrows, and are directed by the valves into the two narrow chimney flues, *g*, *g'* (figs. 169, 173, 174); these open into the general chimney flue, *h*, which may be connected with several furnaces—in which case each furnace must of course be provided with a separate chimney damper, not shown in the drawings.

When the right-hand regenerators have been sufficiently heated by the waste heat of the products of combustion, and the left-hand pair correspondingly cooled by the passage through them of the cold air and gas, the valves are reversed by the hand levers shown in figs. 168 and 173, and the air and gas entering the furnace pass up through the heated right-hand regenerators, while the left-hand regenerators are reheated by the waste heat of the products of combustion. The bed of the puddling-chamber is formed of three cast-iron plates, strengthened by flanges. These bed-plates are covered, as usual, with a layer of calcined tap-cinder, and rest on brick pillars and strong cast-iron bearers. The bed is kept cool by a current of air which enters the air space below it by an opening, *i*, in the back wall of the furnace (figs. 168, 170, 172), and passes out through two air shafts, *k*, *k'*, in the front wall (fig. 170). The back and ends of the puddling-chamber are supported and kept cool by three cast-iron water-boxes, through which a continual current of water is made to circulate.

The sides of the furnace are covered by strong flanged cast-iron plates, bolted together, which are fixed by their lower ends into the pavement, and are bound together at the top by transverse tie-rods; and the whole is braced firmly together by two or more flat wrought-iron bars at each end, which are wedged in between the brickwork of the furnace and the end flanges of the covering plates. There is a pit at each end of the furnace, by which the regenerators are got at for inspection and renewal; the arched roof of the regenerator is carried on through the end wall of the furnace, so that the end wall of each regenerator may be taken down, leaving an arched doorway; and, in order that it may be taken down more easily, it is built in two separate thicknesses of brickwork, and the intervening space may be filled in with sand to prevent leakage.

The saving effected by the use of the regenerative furnaces is not only in the *quantity*, but also in the kind, of fuel which may be used, almost any carbonaceous matter being capable of producing a gas of sufficiently good quality to be employed in them.

The flame may be made reducing or oxidizing at will by suitably

adjusting the supply of gas and air by means of the regulating or throttle valves placed in the gas and air tubes; and by making the first mixture of the gas and air more or less complete, the heating effect of the flame may be concentrated at one point, or diffused uniformly through the whole of a long furnace.

Improvements in Puddling-Furnaces.

Blast under the grate with closed ash-pit.—This application was patented in 1843 by Julius Adolph Detmold,[5] and has been referred to in the First Part of the 'Metallurgy.' The patent was purchased by the Ebbw Vale Iron Company, at whose works I saw it extensively in operation in 1859. The furnaces are built in pairs, side by side; and the blast was conveyed down vertically in iron pipes from a main running horizontally above, between the furnaces of each pair, and entered the ash-pit of each furnace at the side. The ash-pit was closed by folding wrought-iron doors, and the blast was produced by fans. In other respects the furnaces were constructed as usual. Washed small coal was employed as fuel. The patent has now expired. The application of a blast under the grate, with closed ash-pit, in the "working and refining of cast or pig iron, and converting the same from a fluid state into wrought or bar iron," was patented by Peter Onions in 1783.[6]

Blast under the grate with open ash-pit.—I saw this method in operation in 1859, at the Britonferry Iron-works, near Neath, Glamorganshire; and it has recently been adopted by the Ebbw Vale Iron Company. There was a cast-iron pipe, 5 in. or 6 in. in internal diameter, which ascended from one corner of the front of the ash-pit, passed obliquely backwards, and then proceeded at about 8 in. or 9 in. under the grate at right angles to the bars, terminating close to the opposite wall of the ash-pit, to which it was fixed by a nail, passing through a projecting piece cast on its surface at this end. This end was of course closed; but on the under surface there was another projecting piece cast on, in which was fitted a sliding horizontal damper. By drawing out this damper and keeping on the blast, any dust or small ashes which might have accumulated in the pipe could be easily blown out. Along the upper surface of the pipe were three parallel rows of circular holes, about 2½ in. or 2¾ in. apart, and arranged quincuncially. These holes were cast in, and not bored; and their axes were radial, not parallel. It would be desirable that they should widen somewhat towards the interior of the pipe, in order that they might be less liable to become clogged with ashes falling into them. The blast was produced by fans. Small coal was used, half caking and half free-burning.

Air for combustion heated previously by circulation through various parts of the furnace.—The utilization of small non-caking coal or slack in

[5] A.D. 1843, Oct. 18th. No. 9911.

[6] A.D. 1783, May 7th. No. 1370.

puddling-furnaces is a problem of much importance in South Staffordshire and other localities where large quantities of such slack are produced, which, owing to its non-caking quality, cannot be converted *per se* into coke, and has consequently either been left in the pits or thrown away as worthless. Mr. S. H. Blackwell reports favourably of the furnace of M. de Simencourt constructed with this view.[7] I have not given engravings of it; and without engravings it will not be possible to present a satisfactory account. The sides of the fire-grate are formed of perforated blocks of cast-iron. The air, after passing into the ash-pit underneath the bars of the grate, enters partially into the hollow fire-bridge, and through the perforated block attached to it; but the remaining and by far the largest portion of the air passes onwards under the bottom-plates, and after cooling these, enters the hollow flue-bridge, where, becoming divided, it escapes at each end of this bridge into side hot-air flues. These side flues lead into hot-air chambers surrounding the fire-grate, etc. In other respects the construction of the furnace, with reference to the circulating and heating of the air, cannot be understood without engravings. The object is to deliver heated air through the sides of the fire-place. The method is stated to be equally applicable to reheating furnaces. Furnaces of this kind are in operation at Tipton, Staffordshire, in which masses of iron from 2 to 4 tons in weight are heated. M. de Simencourt informs me that in practice he has found it advantageous to have each side of the fire-chamber fitted with cast-iron boshes, containing coiled wrought-iron tubes with water circulating through them. Clinkers are thus prevented from adhering to the sides of the fire-chamber, and the operation of cleaning the grate is thereby rendered much easier. He also uses a hollow water-bridge, through which water is kept circulating.

Puddling with Wood as the Fuel.

In Sweden the process of puddling with wood is conducted in the same manner as with coal, but the construction of the fire-place is modified to suit the charging with this kind of fuel. No Swedish bar-iron, produced by puddling, is exported, the whole of it being retained for home consumption, and worked up into boiler-plates, sheet-iron, rod-iron, and hoop-iron, or used for machinery. It is reported to be of very good quality.

Puddling with Dried Wood.

The process as conducted in Carinthia with dried wood has been minutely described by Le Play;[8] and from his description the following account has been extracted.

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[7] Patented by M. H. de Simencourt and himself, A.D. 1861. No. 1445.

[8] Méthode nouvelle employée dans les Forêts de la Carinthie pour la fabrication du Fer. Paris, 1853. Extracted from the Ann. d. Mines, 5. s. 3.

The special points in this process are the application of wood artificially dried as the fuel, with the addition of a blast, in a furnace otherwise constructed like an ordinary puddling furnace.

In order to obtain the greatest calorific effect from wood in the production of high temperatures, it is necessary to employ it free from hygroscopic moisture.

The modes of effecting desiccation are founded on two principles. According to the first, the gaseous products of combustion of the fire employed to desiccate come in direct contact with the wood, which is thereby exposed to a temperature above 100° C., but not sufficient to cause carbonization; and, according to the second, the desiccation is effected by the heat radiated from pipes either of cast or sheet-iron through which the gases of the desiccating furnace escape.

The fire-place is 0^m 90 (2 ft. 11·43 in.), by 0^m 47 (1 ft. 6·51 in.), and 1^m 60 (5 ft. 2·99 in.) in depth below the arch, or 1^m 39 (4 ft. 6·72 in.) below the fire-bridge. A pipe is connected with the bottom of the fireplace, through which passes air in sufficient quantity to burn the carbon, not escaping as a gaseous product of the distillation, which takes place in the upper part of the fire-place. There is a small passage below the level of the floor communicating with the bottom of the furnace, by which the small quantity of ashes produced may be withdrawn: it is covered over during the time of working. The pressure of the blast which enters the lower part of the fire-place is hardly equal to 0^m 006 (0·24 in.) of mercury.

The air necessary for the complete combustion of the dried wood beyond that which enters below, is thrown in over the fire-bridge, where it joins the body of the furnace, through a flat twyer having about the same width as the stratum of gas to be burned. This second part of the blast first circulates through cast-iron pipes, forming the sides of the bed in which the operation of puddling is effected. The double advantage is thus obtained of keeping the sides of the furnace cool, and of heating the air to about 200° C., and thereby adapting it to act more rapidly upon the gases. The pressure of the blast is 0^m 012 (0·47 in) of mercury, and its direction is such that it would strike the bed at 0^m 21 (8·26 in.) beyond the line extending across the bed from the middle of the working doors. In other respects the furnace resembles the ordinary forms of double puddling furnaces: beyond the bed upon which the puddling takes place, is another small bed upon which a charge of pig-iron is subjected to a preliminary heating, and charged while hot into the furnace. From the second bed the flame escapes into the stack.

Puddling is effected through two doors. A shift lasts 8 hours, and includes 4 heats. The workmen composing a shift are a master man, two assistants, and one stoker.

It is stated that the character of the work only differs from that observed in ordinary establishments where coal is employed in the much

greater facility with which the conversion of pig into malleable iron takes place. Each charge at Lippitzbach consists of

Pig-iron	448 kil.
Scrap-iron (malleable), clippings of sheet	28 ,,
	476 kil.

The average time required to work off a heat completely—that is the period which elapses between the recurrence of the same manipulation in two consecutive heats—is 1 h. 53 min.

The mode of conducting the process is exactly similar to that of puddling in the ordinary way. As there are two working doors, one on each side the furnace, at each of which a puddler works, and as the charge is about double that of an ordinary single furnace in this country, ten balls instead of five are drawn out at each heat; the labour is equally divided between the two puddlers, each doing the same amount of work as an English puddler. At the latter part of the operation, during the formation of the balls, special care is taken not to force the fire; consequently no billets are thrown in, because it is alleged that the contact of gases containing carbon is injurious to the welding together of the iron into balls.

Each charge of 476 kil. gives on an average 455 kil. of puddled iron. The production per week amounts to 29,100 kil. For each metrical quintal (*i.e.* about 0·1 ton English, short weight) of crude puddled iron 1·011 of dried wood is consumed. The wood employed is a mixture of *Pinus sylvestris*, *Abies excelsa*, and *Fagus sylvatica*. The cubic metre weighs 395 kil.

The mill or reheating furnaces are constructed on the same principle as the puddling furnaces. Instead of throwing a blast into the fire-place, the air may enter by an ordinary grate, the draught being effected by the stack; and, indeed, the same arrangement may be used in the puddling furnace. At Lippitzbach each kind of furnace is employed indifferently either for puddling or reheating.

Stamping and Assorting Puddled Balls.

This process, which was patented by William Taylor,[9] has been practised at the Low Furness Iron and Steel-works, under the management of Mr. Davis, from whose son, Mr. J. F. Davis, my former pupil, I have received the following account. The puddled balls, instead of being shingled, etc., as usual, are left to cool, and when cold they are crushed under steam stamps and then ground between cast iron rolls, weighing about 2 tons each, and working over a bed formed of perforated (cast?) iron plates. Two products are thus obtained: one termed "good iron," which crushes easily and passes through the holes in the bed; and another termed "raw iron," or "greys," in round lumps, about the size of common marbles, which does not crush easily, and re-

[9] A.D. 1855, Nov. 1, No. 2439. In the specification the ball is directed to be thrown into water and so cooled.

mains upon the bed. The "good iron" is greyish black, and has the appearance of a well puddled ball reduced to particles about as large as peas. The "greys" are lighter in colour, and feebly metallic in lustre on the exterior; and when broken, as they may be without difficulty by a hammer, the fracture exactly resembles white pig-iron, and the metal is slightly malleable on the edges. These are evidently imperfectly converted pieces, and are, consequently, re-puddled. The "good iron" is worked up directly into balls and shingled, etc. The object, then, of this process is to separate the iron not perfectly "come to nature" from that which is completely converted, so that by balling the latter apart, iron more homogeneous in character may be obtained than would otherwise be the case. The process must necessarily entail considerable additional expense; and I believe it has been abandoned. The iron produced from the second balls seldom required piling, except for very extra purposes. On showing some of the "greys" to Mr. Joseph Hall, of the Bloomfield Iron-works, he remarked that they could only result from bad puddling.

Östlund's Process of Puddling.

Mr. Grill has communicated to me a short notice of this process, which has been devised by Mr. Östlund, of Sweden. "The ores of Sweden," Mr. Grill writes, "being remarkably free from phosphorus, yield much more refractory pig-iron and malleable iron than those of most other localities, which consequently must be treated in a different manner from less refractory kinds of metal. In puddling the better sorts of charcoal pig-iron, the walls of the furnaces will not support the high temperature necessary. On this account Mr. Östlund's method seems preferable. He proposes to refine the iron in a revolving iron pot, lying in an inclined position, and heated by a blow-pipe with carbonic oxide. The revolving of the pot will perform the work of the puddler, and prevent the sides of the pots from ever losing their coating of cinder, of which the effect will be to yield much cleaner iron or steel than from an ordinary puddling furnace." Mr. Grill considers this method as extremely promising for the conversion of Swedish pig-iron into malleable iron. I fear, however, that my friend's hopes will be disappointed.

Utilization of the Waste Heat of Puddling Furnaces.

Every reflective person who has passed, especially at night, near puddling furnaces in operation, must have been struck with the enormous amount of heat allowed to escape uselessly into the air, as evidenced by the long column of red flame from the chimney tops. The waste of heat which has thus occurred in Great Britain alone is inconceivably great. Every particle of that heat is so much power, derived originally from the sun, and stored up with extreme slowness in our coal-beds during the vast period of time required for their formation. The extent to which that power has been squandered will no doubt excite the ire of our successors, who will feel that they

have been unjustly deprived of a rich inheritance, as represented by coal, either through wilful prodigality or stupid ignorance. Happily, from one cause or other, not excepting the most potent of all, necessity, economy is at length beginning to be practised with respect to fuel. The time will come when many an old coal-pit now abandoned as utterly worthless will be regarded as a valuable mine, and worked over again with great advantage.

The utilization of the waste heat of puddling furnaces has, so far as I am aware, related almost exclusively to the raising of steam, and numerous contrivances have been adopted with that object, several of which I will now describe.

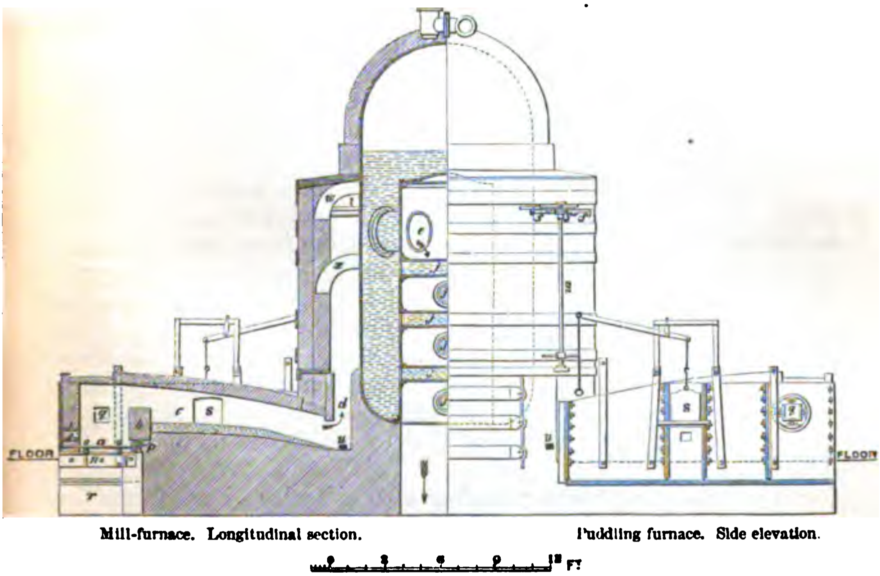
The flame has been made to pass directly from the body of the furnace under a steam-boiler set horizontally at the end of the furnace, the draught, of course, being duly promoted by a stack. I saw this method at Mr. Nevill's forge at Llanelly.

At a short distance above the furnace, the stack for a considerable height has passed through a wide central vertical flue in the middle of a cylindrical boiler. An arrangement of this kind might be seen at the Albion Iron-works, West Bromwich.

A boiler has been fixed horizontally above each puddling furnace. The boiler was cylindrical, and at one end was turned down for a short length at right angles. It was traversed by a circular flue, and the turned down end was set over the flue. I saw this arrangement at the Blaenavon Iron-works, of which the forge was newly built at the time of my visit in 1859. The boilers were not then jacketed to prevent radiation, as, I presume, they have since been; but, whether jacketed or not, much heat must be radiated down upon the head of the puddler. This system moreover is, Mr. Menelaus observes, objectionable, as in multiplying the number of boilers it increases the cost of repairs and attendance. I am informed that a similar arrangement had been tried at the Abersychan Iron-works (now belonging to the Ebbw Vale Iron Company) and abandoned, especially on account of the serious inconvenience which the puddler experienced from the radiant heat.

A method, which has been adopted at several Iron-works, is represented in the accompanying engraving, fig. 174, executed from a drawing, for which I am indebted to Mr. Levick, at whose Iron-works at Blaina and Cwm Celyn it is in extensive operation. In South Staffordshire I have seen it in use at the Bromford Iron-works more than 20 years ago. The left half of the engraving is in vertical section, and the right half in elevation. The boiler is cylindrical, egg-ended at the top, but flatter at the bottom. At a certain distance below the water line is a circular vertical descending flue of boiler-plate, which communicates with an underground flue connected with a high stack, as indicated by the arrow pointing downwards. Into the upper part of the descending central flue, four circular transverse flues, *e*, enter from the outside; and each of these communicates with a furnace, either for puddling or reheating. The descending central flue is traversed by six pipes or small flues, *j*, *j*, *j*, etc., crossing over each other at

right angles, thus increasing the area of the heating surface, and serving to strengthen the boiler. The boiler is set on a firm foundation of brick or stonework, and is surrounded with a circular wall, concentric with the boiler, a considerable flue space being left between the two. This space is covered in at the top by the arch, *w*, and is divided below by four vertical brick pillars into equal and similar spaces, which communicate respectively with the flues, *d*, of four furnaces, two on each side. There are four arches, *x*, immediately under the transverse flues, *e*, and extending only a little beyond the sides of these flues. Above and on each side of these lower arches, *x*, is a vertical wall (which is shown white, but should have been shown as brickwork), thus enclosing a space corresponding to the openings of



Mill-furnace. Longitudinal section. Puddling furnace. Side elevation.

Fig. 174. Application of waste heat of puddling and mill furnaces to the raising of steam.

the transverse flues, *e*. At the top of this space is a horizontal damper, *f*, which may be opened and closed by the rack, *f′*, and pinion, *f″*. The pinion is fastened on one end of the vertical shaft, *m*; and on the other is a lever for moving the pinion, which acting upon the rack opens or closes the damper. The pulley keeps the rack and pinion in gear, and runs loose on a pin. The flame then rises on each side of the arch, *x*, and descends in the manner indicated by the arrows. The upper part of the boiler is jacketed with brickwork.

The furnace in elevation on the right is a puddling furnace, and that in section on the left a reheating or mill-furnace.

a, Fire-grate; *b*, Fire-bridge; *c*, Body of the furnace; *n*, Brackets fastened on the side-plates of the furnace and supporting the bearers,

o, o, on which the fire-bars rest; *p*. Bearer supporting the fire-bridge; *q*. Stoke or fire-hole; *r*. Ashpit; *s*. Charging door; *t*. Cast-iron bearers carrying the brickwork above; *u*. Holes to allow the cinder to run off.

According to the experience of Mr. Arkinstall, of the Bromford Iron-Works, boilers thus heated by the waste flame of puddling and mill furnaces require great care in their management; otherwise the advantage gained by the application of the waste heat in raising steam may be more than counterbalanced by the disadvantage of the irregularity of action induced in the furnaces and the difficulty of properly regulating the draught. The mill-furnace being always the hottest has a stronger draught than the puddling furnace, and the working of the latter, it is maintained, will be checked in consequence. Mr. Levick expresses himself perfectly satisfied with their action. He has never known an explosion to occur with these boilers. The transverse pipes, however, are liable to become stopped up with deposit.

Mr. Menelaus has (July, 1863) communicated to me the following important information concerning the system of economising the waste heat of puddling and reheating furnaces recently adopted at the Dowlais Iron-works.

"No ordinary boilers," he writes, "are so economical in raising steam, in attendance and repairs, as the ordinary large Cornish boiler, which may be placed quite clear of the forges, and in no way interfering with the comfort of the men. The problem was to apply the waste heat of the puddling and balling (*i.e.* reheating) furnaces to the production of steam in an ordinary Cornish boiler, without in any way interfering with the working of the furnace, and, at the same time, removing the boilers from the forge, so as to ensure safety to the men in case of accident, and leave a clear, open space under the roofs to secure thorough ventilation, and thereby comfort to the men in hot weather.

"The boilers have been placed at a considerable distance from the forge, where, to produce a good draught, a large stack, 12 ft. square and 150 ft. high, was built. Two culverts of about 60 ft. area each were carried through the forge underground, and the flues of the furnaces turned down into them. The culverts are connected directly with the boiler tubes, the heated gases carried round the boiler and flues in the usual way, and taken off, after doing their work, into the stack above mentioned, which, from its height and large size, ensures plenty of draught. The result is that there are no chimneys whatever in the forge, and there are no surfaces to give out heat, except the furnaces themselves. The weather is now excessively warm, and while the men in the other forges are partially broiled, in our new forge with the above arrangements they are working with tolerable comfort. There is nothing new in the scheme: it has been tried over and over again; but, I believe, through imperfect arrangements, it has never succeeded well, except at Ebbw Vale and with us. The utilization of the heat in this manner no way affects the working of the furnaces. The improvement and saving are so marked, that we are giving the matter at present all our attention."

WORKING OF THE BALL.

I have already described, in as condensed a manner as I could, the working of the ball produced in the charcoal finery under the hammer; and I have given an engraving of the hammer used in Sweden for this purpose. Formerly, the hammer was the only instrument employed in this and other countries for converting the ball so produced into bar iron. But it was proposed, as we have seen, even before the introduction of the process of puddling, to substitute notched or grooved rolls in great measure for the hammer. The Ball, when it leaves the furnace, is a spongy mass, consisting of particles of malleable iron feebly cohering, and infiltrated throughout with liquid cinder. By hammering, those particles are welded into a solid oblong, more or less rectangular slab of iron, the cinder being thereby more or less completely squeezed out. This manipulation, as previously stated, is termed shingling, and the man conducting it a shingler. It was not intended to resort to the grooved rolls until after the ball had been thus fashioned under the hammer; nor at any time subsequently has any ball, whether produced in the charcoal finery or the puddling furnace, been otherwise treated in the first instance than by compression either under a hammer, or a special squeezing apparatus, whereby it might acquire solidity before passing between, or as it is termed, through the rolls. We have, therefore, first to consider the machinery adopted for this preliminary treatment, and afterwards that for rolling. Under the first heads are comprised hammers and squeezers. I may here define the meaning of two words, which I have already many times used, Forge and Mill. The Forge is that part of an iron-work where the balls are hammered or squeezed, and then drawn out into puddled bars by means of grooved rolls; and the Mill is that part where these bars by manipulation, presently to be described, are converted into merchant iron, whether in the form of bars, rods, or sheets.

FORGE-HAMMERS.

Forge-hammers are divisible into two principal classes, viz., the lever-hammer, in which the hammer-block is fixed to one end of a shaft placed horizontally, and is moved vertically through a small arc by a rotary cam shaft; and the direct acting or stamp hammer, where the hammer-block is lifted vertically, either by cams or friction rollers, or, as is more commonly the case, by steam or water pressure acting on a piston in a closed cylinder. The lever-hammer is further classified, according to the relative position of the hammer-block, the cam ring, and the centre of oscillation, into tilt-hammers and helves.

1. *Tilt-hammers.* The centre of oscillation is placed between the hammer-block and the lifting cam, the former being at the end of the longer arm, and the latter at the end of the shorter arm of a lever of the first order.

Tilt-hammers are comparatively of small size, and are made with small hammer-blocks from 1 to 5 cwts. in weight. They are usually driven at considerable speed: the force of the blow is sometimes increased by

the use of a wooden spring beam for accelerating the speed of the hammer during its descent.

2. *Helves, or lift-hammers.* The cam ring and hammer-block are on the same side of the fulcrum or axis. Here, again, two cases are to be distinguished, viz., that in which the hammer-block is placed between the lifting cam and the axis, a form to which the name of head-lift helve may be given; and that in which the cam wheel works on a lifter placed between the hammer-block and the axis of oscillation; this construction is known as the "belly helve." Helves are now entirely made of cast-iron, with shifting wrought-iron striking faces.

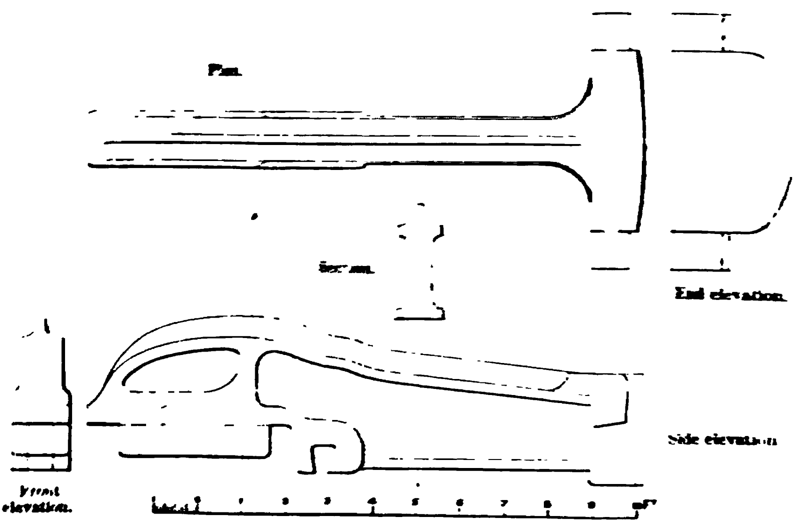


Fig. 175. Helve at the Mersey Steel and Iron Company's Works.

Fig. 175 represents a belly helve used at the Mersey Steel and Iron Works, for drawings of which I am indebted to Mr. William Clay. The engravings are sufficiently detailed to require but little verbal description. It is a solid casting of a T shape in plan, weighing about 10 tons; the journals at the end of the shorter or cross arm rest in open bearings, carried on massive cast-iron framings. The cross arm is of great thickness, in order to resist the tendency to horizontal motion produced by the cams of the lifting wheel. The small dovetail-groove near the centre of the helve forms the seat for the lifter, which is acted on by the cams; it is made of wrought-iron, and can be easily shifted and replaced when worn out. The hammer face is made of wrought-iron, and is attached to the helve by a dovetail-groove and wedge; the anvil is faced in a similar manner. The moving mass of the hammer weighs 10 tons; the height of lift is from 18 to 24 in.; the maximum working speed is 60 strokes per minute. It was employed for forging the large Horsfall 13-inch gun, weighing 27 tons in the rough state, probably the largest mass ever wrought under a lever hammer.

The framings and foundations of this hammer are not specially described, as that subject may be more usefully considered under the head of Steam-hammers, and will be given in the sequel. The chief advantage of the belly-lift over the head-lift form of helve is that the anvil stands in front of the rotary cam shaft, usually the most massive part of the machine, and leaves three sides free for working. The head-lift helve is, however, more commonly employed, being somewhat simpler in construction.

An ordinary hammer face in constant work will only last from three to seven days, according to the quality of the metal operated upon; and the anvil face, under similar conditions, will last about the same time. Attempts have been made to lengthen the period of service of these faces by causing water to circulate through them, thereby keeping them cool. Mr. Arkinstall states that a hammer face thus cooled will last ten times longer than one without this arrangement. It would, however, appear that this system of cooling is attended with practical inconveniences which have not as yet been satisfactorily overcome, as in works in which it has been tried it has been generally abandoned.

Steam Forge-hammers.

Of late years the various forms of tilt and other lever hammers or helves have to a considerable extent been replaced in the majority of English forges by the direct acting steam-hammer, a machine which was originally proposed by James Watt in 1784, afterwards sketched nearly in its present form by Deverell in 1806, but which was first reduced to a practical form by Nasmyth in 1842.

This admirable and invaluable machine is now extensively employed in shingling and forging iron. Balls, which would crumble to pieces under the helve, may, by gently regulated blows under Nasmyth's hammer, be easily wrought into solid blooms or slabs. The kind of hammer employed, therefore, may furnish indications as to the quality of the iron composing a ball. With the helve, "coaxing" or "humouring," as it is termed, is impossible; and a ball, in order to support its dead, heavy blow, must be made of tolerably good iron. Not so, however, with the Nasmyth's hammer. By these remarks, it is far from my intention to insinuate that this machine is only resorted to in the case of balls made of iron of inferior quality; for I know that in many cases the contrary is the truth.[1]

In its original or single-acting form the steam-hammer consists of a heavy block moving between guides attached to the piston-rod of a vertical steam-engine, of which the piston is lifted by high-pressure steam acting on its lower surface. When the piston has reached the top of its stroke, the blow is given by allowing the steam to escape freely into the atmosphere, when the hammer, being no longer supported, falls on the anvil with an impact due to the gravitating action of its mass falling through a height equal to the length of stroke of the

[1] For the following description of steam forge-hammers I am indebted to my former student and friend Mr. Hilary Bauerman.

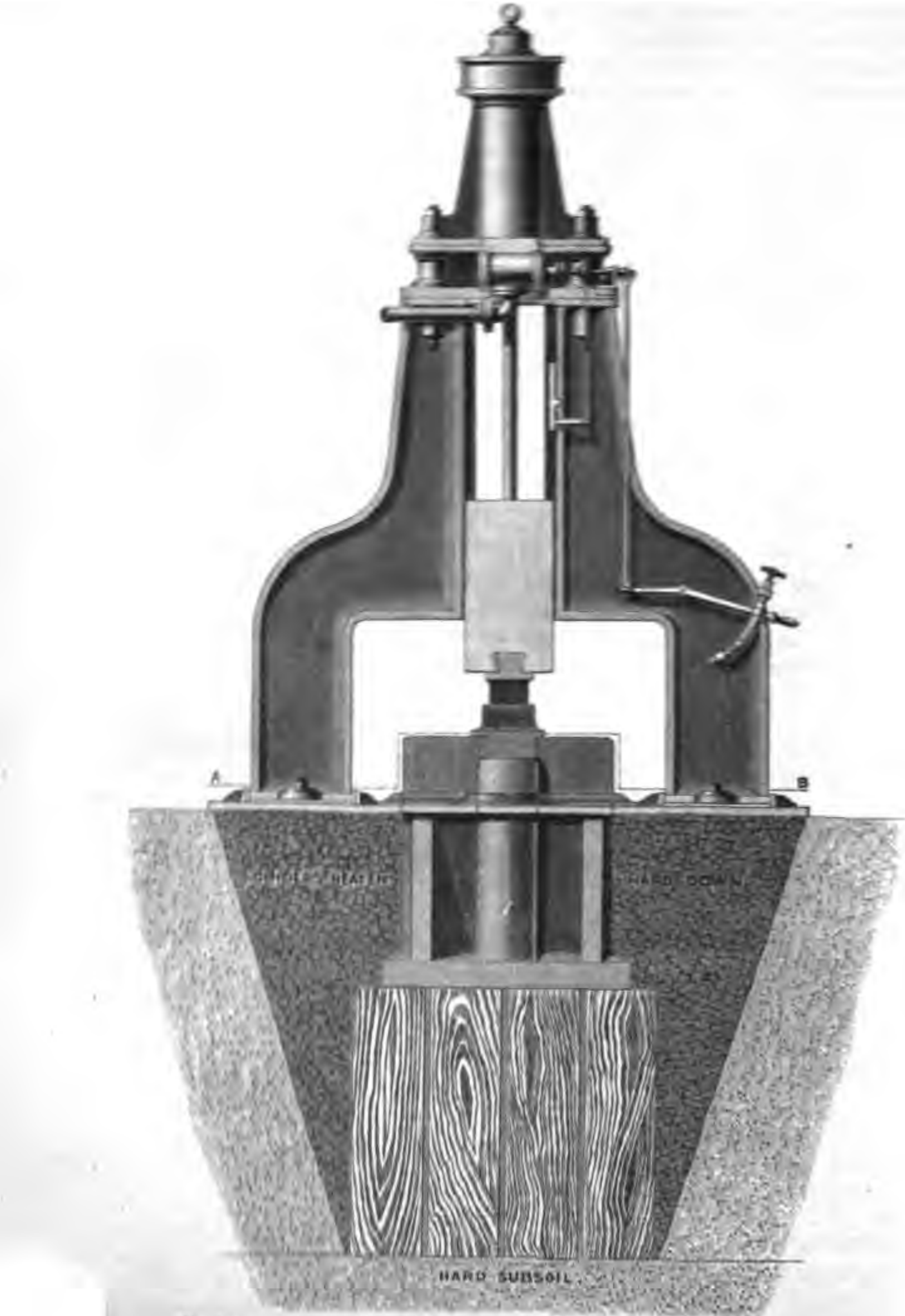


Fig. 178. Nasmyth's Hammer. Front elevation.

piston. In the double-acting hammer the force of the blow is increased by allowing the steam to act on the upper surface of the piston, in order to obtain a greater velocity at the moment of impact than can be obtained by the gravitating action of the hammer-block alone. The

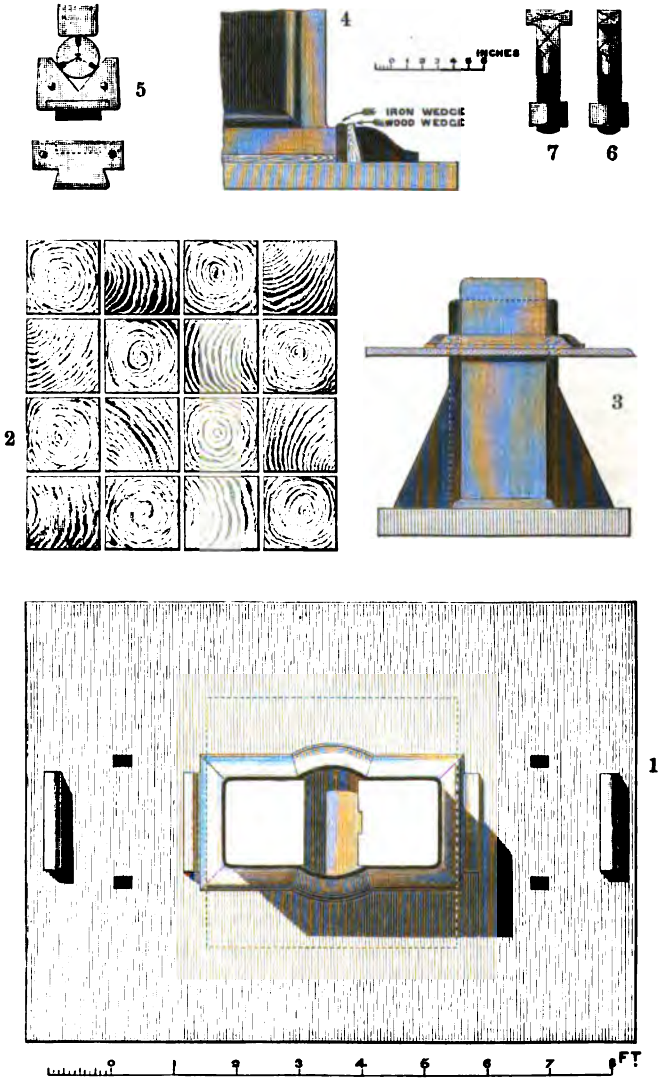


Fig. 176a. Nasmyth's Hammer. Plan and details.

double acting or "top steam" form of construction is almost universally adopted in the more modern hammers, the valves being usually so arranged that the steam can be used either on the lifting side only, or on both lifting and striking portions of the stroke at pleasure.

Of the various modifications of form used at the present time three may be selected as typical, namely, the original Nasmyth hammer, Messrs. R. Morrison and Co.'s pattern, and that introduced by the late Mr. John Condie. In the Nasmyth hammer the block travels on parallel guides attached to the framing below the steam cylinder. Morrison's hammers have the guides placed above the cylinder; the piston-rod, which is welded together with the piston and block into a single mass, is carried through both cylinder covers, an arrangement having for its object the increase of stability by lowering the centre of gravity of the machine. In Condie's system the hammer guides are in an intermediate position between those of the two former systems; that is, they are in the line of the side of the cylinder itself, an arrangement which is obtained by the use of a fixed piston attached by a tubular rod to the top traverse of the framing, combined with a moveable steam cylinder, which is cast in one with the hammer-block. By this system of construction the apparent action of the steam is reversed, the lifting being effected by steam admitted above the fixed piston, the lower side of the moving piston in the other systems being here represented by the under surface of the top cylinder cover.

Nasmyth's hammer.—A double acting steam-hammer of 15 cwt., erected by Messrs. James Nasmyth and Co., at the Atlas Works, Sheffield, is shown in figs. 176, 176*a*. Fig. 176 is a front elevation of the hammer and anvil, with its foundations. Fig. 176*a* is a plan and details. 1. The plan of the sole-plate and anvil; 2. The plan of the vertical wooden baulks which carry the anvil; 3. The end elevation of the anvil; 4. An enlarged view of the junction between one of the hammer standards and the sole-plate, showing the wooden packing and the method of fastening by means of wrought-iron and wooden wedges; 5. A swage face, which is fixed to the anvil instead of the ordinary flat face piece when the hammer is used for forging round bars; 6 and 7. Enlarged views of one of the holding-down bolts by which the hammer is fixed to the sole-plate. The hammer-block weighs 15 cwts., having a maximum length of stroke of 40 in. The weight of the anvil is about $5\frac{1}{4}$ tons: it rests on a bed formed of 16 upright square baulks of timber of a total content of about 84 cubic feet. The sole-plate measures 9 ft. 9 in. by 7 ft. 1 in., giving a surface of more than 60 square feet: it rests upon a bed of broken cinders. A clear space of $\frac{3}{16}$ of an inch is left all round the anvil, where it passes through the sole-plate. The framings of the hammer allow of a working space of about 5 ft. in length by 2 ft. in height.

Condie's hammer.—In fig. 177 a Condie hammer of the largest class is represented in front and end elevations. The framing consists of two vertical cast-iron columns of rectangular section, A B, bound together laterally by a strong cast-iron transverse beam, C, with a central ring opening for the passage of the cylinder or hammer-block. The lower columns are surmounted by an arched girder of similar section, D, which is put together in three segments, the top casting carrying an entablature to which the steam-valves and the gearing

for moving them are attached. The cylinder E, with its attached hammer-block weighing 15 tons, is made of toughened cast-iron: it moves between vertical guides F F, bolted to pillars extending from the top of the horizontal cross-girder C to the under side of the crown of the arch of the top framing. The piston-rod G, which is hollow, and serves also for the admission and exhaust steam passage, is attached to the entablature by a ball and socket joint; it is formed of two concentric tubes: the outer one, reaching from the top of the framing nearly down to the top of the fixed piston, forms the steam passage for the lifting portion of the stroke, while the inner one or piston-rod proper serves at the same time as the point of support for the piston and the passage by which the steam is admitted and exhausted on the under surface of the piston during the driving portion of the stroke.

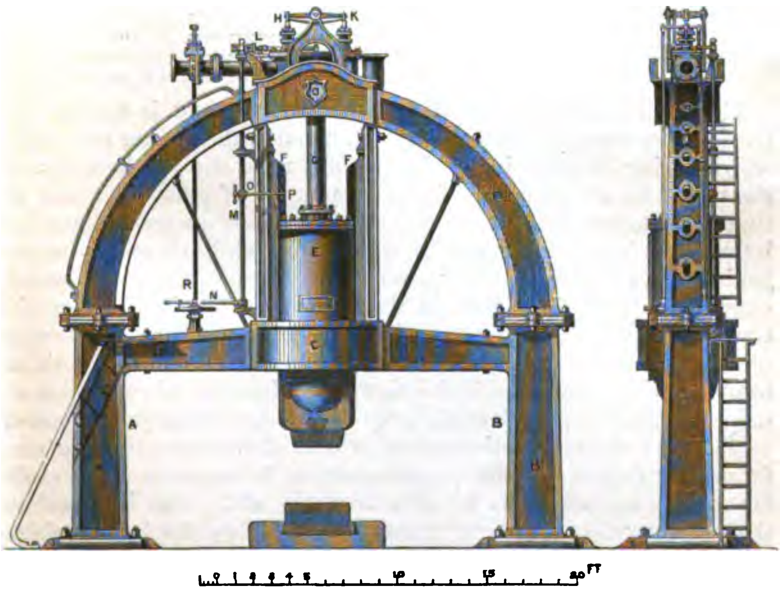


Fig. 177. Condie's Hammer. Front and end elevations.

The admission and exhaust steam-valves are fixed to the opposite ends of an equal-armed beam, which is moved by an arrangement of angle levers from the vertical shaft M, which turns in bearings fixed to the left-hand guide frame. Two levers are attached to the vertical shaft: the lower one, N, is used for moving the valve by hand; the upper one, O, slides on the vertical shaft, and can be adjusted for regulating the length of stroke by a clamp-screw moved by a hand-wheel. The opposite end of the arm, O, carries a roller, which resting on the surface of the inclined block or wedge L attached to the left-hand side of the cylinder, causes the shaft M to turn about its axis as the arm O is pushed out by the action of the wedge during the ascent of the

[illegible] a motion which opens the exhaust valve and allows the hammer to fall. In the hammer under description the valves are not moved directly by the vertical shaft and levers, a small horizontal steam-engine being employed for that purpose. The duty of the [illegible] gear is therefore confined to moving the slide valve of the auxiliary engine.

The admission steam-valve is a balanced many-ported cylinder valve so arranged that by turning it half round against its seat the hammer is made single or double-acting at pleasure.

The following are some of the principal dimensions of the hammer above described:—

Weight of hammer-block	[illegible] tons.
Length of stroke	[illegible] feet.
Working steam pressure	[illegible] lbs. per sq. inch.
Distance between vertical frame plates or working space	[illegible] feet.
Height from floor to top of framing	[illegible] "
Weight of superstructure, including sole-plates	[illegible] tons.
Weight of anvil	[illegible] "

The anvil is of the form of a truncated cone, and is cast in two portions, the larger one is conical and tubular, the greater part of the weight being disposed in the broad solid mass closing the bottom of the tube; the second portion forms a cap or lid of great thickness, fitting on the top of the lower casting; the two parts are secured together by wrought-iron links or glands, which are tightly shrunk on to projecting studs disposed radially around the outer circumferences of both castings. The hollow space in the bottom casting is filled up with concrete. The whole mass stands on its own platform, and is completely isolated from the surfaces bearing the superstructure. Both the hammer and anvil are provided with wrought-iron face pieces, which are united to their respective castings by dove-tailed wedges and grooves.

Hammers similar in dimensions to that above described are used for making forgings of the largest class, as for example crank shafts for marine engines, piles for armour-plates, etc. The intermediate shaft of the 'Great Eastern' steam ship, probably the largest single crank shaft ever forged, weighing 31 tons 2 cwts., was forged under a single acting 6-ton Condie hammer by the Lancefield Forge Company.

From $1\frac{1}{2}$ to $3\frac{1}{2}$ tons is the weight of the hammers usually employed in iron-works for making puddled blooms and slabs of ordinary dimensions; from 11 to 15 puddling furnaces may be served by one 50-cwt. hammer, the necessary steam being obtained from the waste heat of two reheating furnaces.

Tunner gives an example of a 95-cwt. Condie hammer at Steyer,[1] making 50 to 60 4 ft. strokes per minute, which does the blooming and welding for two double puddling and two reheating furnaces, the steam being generated in two boilers, each 22 ft. long and $3\frac{1}{2}$ ft. in diameter, by the waste heat of a single reheating furnace.

An elaborate mechanical analysis of the steam-hammer, as well as of the various forms of lever-hammers, is given by Weisbach.[2]

[1] Jahrbuch, vol. iv. [2] Ingenieur und Maschinen Mechanik, 3. pp. 1270-1340.

Patents relating to Steam-hammers.

These have been selected to show the progress of invention from the single to the double acting hammer. The extracts refer to hammers lifted by steam pistons only, and not to stamp-hammers lifted by cams or other rotary mechanism.

James Watt. *April* 28, 1784. No. 1432.—In this specification, which is of a very comprehensive character, being mainly occupied with transmission and change of motion in steam-engines, is described a plan for moving hammers by steam-engines without the use of rotary motion either by attaching the piston direct or using a helve or lever, and working the helve by a strap or rod attached to the end of the working beam opposite to the steam cylinder. The direct-acting modern form does not here appear to have been contemplated, if we may judge by the illustrative figure which represents a small forge-helve of 5 cwt., which is lifted by a rod in the position of the connecting rod in an ordinary rotary beam-engine. The diameter of the piston is stated to be 15 in.; the engine is single-acting and condensing; the force of the blow is increased by a spring beam which drives the hammer down, according to the construction then current in most European forges.

W. Deverell. *June* 6, 1806.—This patent contains projects only, and is not illustrated; it includes many ideas that have been revived in later times, such as the use of solid hammer bars, high-pressure steam and compressed air for the return stroke, as shown in the following extracts :—

"At the end of the rod that comes out of the cylinder is a hammer either made fast to the rod by welding or in any other proper way.

"The steam from the boiler is let in underneath the piston ; the air at the top of the piston will then be compressed by the superior pressure of the steam. After the piston has been raised to a given height there will be an opening made from the under side of the piston to a vacuum, or the steam may be let out into the common air; the compressed air at the top of the piston will then drive down the hammer with a velocity equal to what it may be compressed.

"The weight of the hammer may be made equal to the pressure of the steam, so as to work without springs."

James Nasmyth. *June* 9, 1842.—Contains the first drawings of the perfected single-acting hammer. The method of employing a steam-cushion at the change of stroke and top steam for the down stroke is noticed, but said not to be as advantageous as the more simple construction.

James Nasmyth. No. 9850. *Jan.* 4, 1843.—This patent contains the steam pile-driver, and describes, among other modifications in the construction of steam-hammers, a plan for the use of an air or steam-cushion on the upper face of the piston for the purpose of limiting the up stroke and adding force to the descending piston at the commencement of its fall.

John Condie. No. 11,411. *Oct.* 15, 1846.—Contains the first description of the single-acting moving-cylinder hammer with compressed air-cushion; also describes a plan for cooling the faces of hammers, squeezers, and anvils, by a current of water circulating through them.

[illegible]

[illegible]

[illegible] 4. Arrangement of the [illegible] [illegible].

[illegible] No. [illegible] 1854.—This patent revives the idea of the condensing hammer, the down stroke being made against a vacuum produced in a condenser of a very peculiar construction. A strong steel spring is placed at the top of the cylinder for the double purpose of accelerating the down stroke and stopping the lift. The piston-rod is formed of two pieces, a tube which forms the guide working through the packing in the stuffing-box and an internal solid rod, one end of which carries the hammer, while the other is attached to the piston by a ball and socket-joint.

W. B[illegible]. No. 25. Sept. 3, 1854.—The distinguishing feature of this construction is the suppression of the guides. The piston is kept straight by the use of an elliptical or polygonal rod working through a stuffing-box of a corresponding form. Owing to the great thickness of the rod the under surface of the piston is much smaller than the upper surface; the steam used at full pressure for lifting is afterwards used expansively on the top of the piston for driving.

W. NAYLOR. No. 2419. Oct. 30, 1855.—A double-acting hammer, working with full-pressure steam on both sides of the stroke, contains a plan for preventing the piston from turning when no parallel guides are used by attaching it eccentrically to its rod. The specification also contains a description and figure of a horizontal hammer to be used as a riveting machine.

Other steam-hammers have been patented, but scarcely any of them require particular notice. There is, however, one which should not be passed over without comment: it is that patented by P. A. Le Comte de Fontainemoreau,[4] a well-known name in England in connection with patents. It is gravely proposed that in order to prevent cooling, the operation of forging should take place in the interior of the furnace (!). For this purpose a vertical steam-hammer passes through the furnace, into which the anvil also projects from below. The scheme might possibly succeed if the hammer and anvil were formed of a metal which would neither oxidize nor soften at high temperatures; but with hammers and anvils of iron the idea is so absurd that it is difficult to conceive how any person, having the slightest knowledge of the properties of iron, should ever have propounded it.

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[4] Improvements in forging iron, A.D. 1855, Sept. 27. No. 2152.

SQUEEZERS.

Crocodile squeezer.—The accompanying engravings, figs. 178, 179, have been executed from drawings of one of these machines at the Bromford Iron-works, prepared under the direction of my excellent friend, Mr. George Shaw, of Birmingham. A ball is shown in its proper position. The action of the machine will be perfectly intelligible, without any elaborate description. The upper jaw alone is moveable, and it is ribbed or serrated on its under surface, where it comes in contact with the ball. The term, crocodile, is with propriety applied to this kind

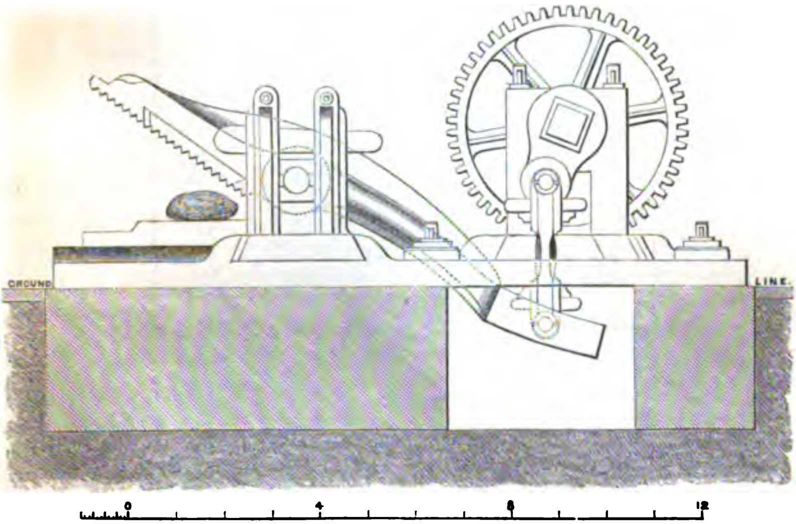

Fig. 178. Crocodile Squeezer. Side elevation.

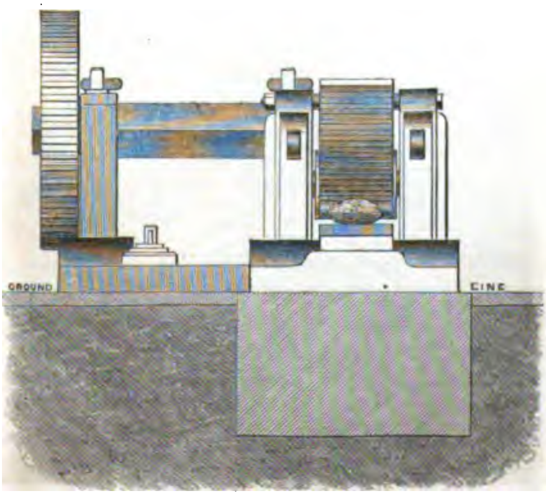

Fig. 179. Crocodile Squeezer. End elevation.

of squeezer, as, I think, will be admitted from an inspection of the engravings. The first squeezer mentioned in the Abridgments of Specifications relating to the Manufacture of Iron and Steel is that of John Harvey.* Squeezers, variously modified in minor details, are very extensively employed, as, for example, in the Rail Mills of South Wales. In 1854, Mr. W. H. Brown, proprietor of the Bromford Works, obtained a patent for working blooms by the combined operations of squeezing and subsequent hammering.*

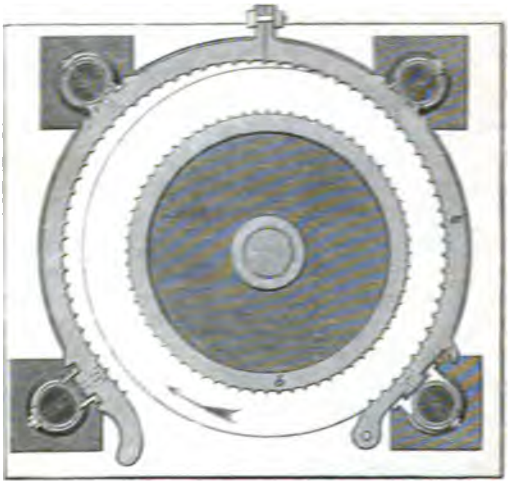

Fig. 160. Rotary Squeezer. Horizontal section on the line A B, fig. 162.

Fig. 161. Rotary Squeezer. Plan.

* A.D. 1805, Nov. 7. No. 2888. * A.D. 1854, Sept. 19. No. 2019.

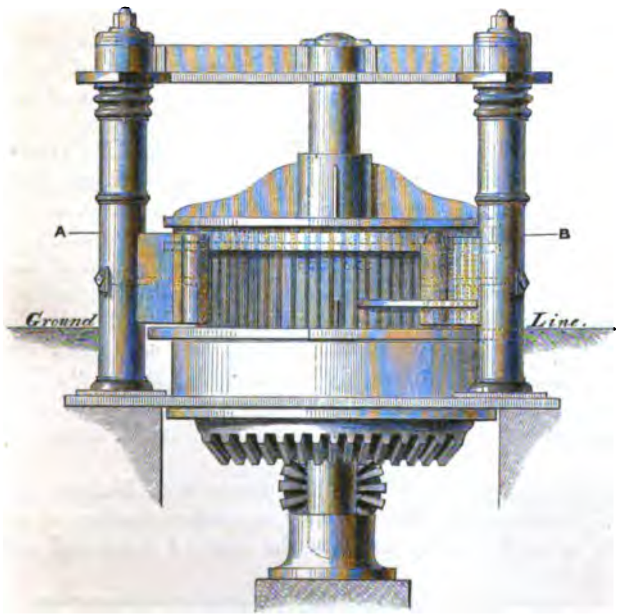

Fig. 182. Rotary Squeezer. Front elevation.

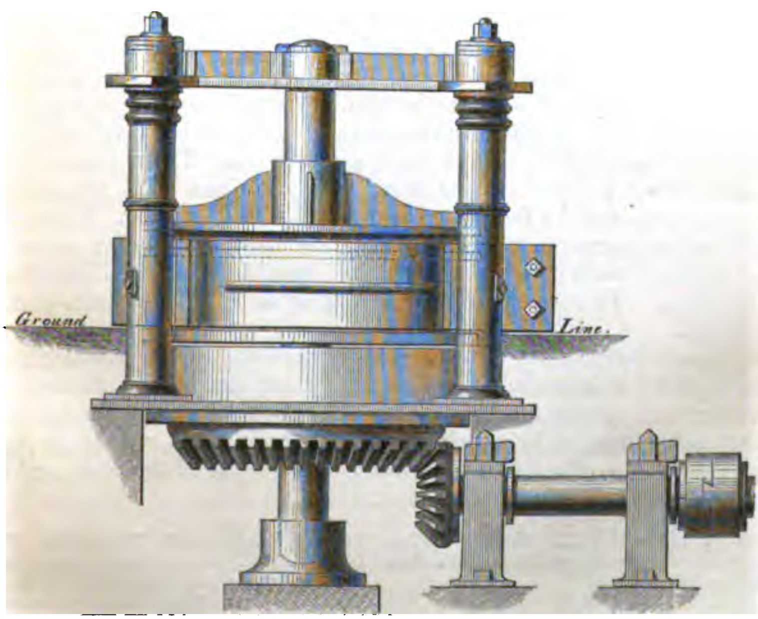

Fig. 183. Rotary Squeezer. Side elevation.

Horizontal Rotary Squeezer.—It is an American invention, and was patented by Gerard Ralston in 1840.[7] The accompanying engravings, figs. 180 to 183, have also been executed from drawings of this machine at the Bromford Iron-works, prepared under the direction of my friend, Mr. George Shaw. It consists of a strong cast-iron wheel, fig. 180 *b*, ribbed or serrated on its outer surface, which has its axis vertical, and revolves eccentrically within a strong cylindrical cast-iron frame, also ribbed or serrated on its internal surface, fig. 180, *a*. The ball is introduced in the position of the arrow, fig. 180, when it is immediately caught by the wheel rotating in the direction of the arrow, and is carried round, becoming more and more compressed in its course, until it nearly reaches the place where it entered, when it is upset by a catch, shown in figs. 181 *c* and 182, and taken away. It leaves the machine in a roughly cylindrical form or "roll," and is immediately afterwards passed through the puddle-rolls, when a further amount of liquid cinder is extruded from it, especially along the axis.

Vertical Rotary Squeezer.—In 1843 a patent was obtained by George Benjamin Thorneycroft for a rotary squeezer similar to that last described, with the exception that the axes of the wheel and frame were horizontal.[8]

Mr. John Arrowsmith has recently patented a squeezer on the same principle, which I have seen in operation at the Bromford Iron-works; but its working was not altogether favourable, and the old machine with the axes vertical was preferred.

In 1857 a patent was granted for "Improved Machinery for Blooming Iron."[9] It consists essentially of two vertical rotary squeezers, one immediately over the other, and so forming, as it were, one continuous squeezer. The ball is put into the upper part of the machine, and, as it leaves this at the bottom, it drops into the lower part or second squeezer, of which the eccentric roller or wheel revolves in an opposite direction to that of the upper squeezer. The upper concave frame or box forms the letter S with the lower one. The rollers and inner surfaces of the frames are serrated or ribbed as usual. There are convenient arrangements for raising the ball, etc., for an account of which I must refer to the original specification and illustrative drawings. This squeezer has been tried at Highfields Iron-works, Bilston.

Brown's Shingling Machine.—A patent was obtained for this machine in 1847.[10] It is ingenious and effective, but has become unpopular, owing to frequent breakages. Mr. Menelaus, however, informs me that in his opinion, by suitable modifications it would answer its purpose well. Mr. Fairbairn considers it to be "one of the most perfect

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[7] A.D. 1840, Feb. 22. No. 8389. "Improvements in rolling puddle-balls or other masses of iron."

[8] A.D. 1843, Dec. 28. No. 9996.

[9] To James Abbot, jun., Richard Handley Thomas, John Young, and James Edward Hunt. A.D. Nov. 1857. No. 1423.

[10] Machinery for Squeezing, Rolling, Doubling, and Piling Iron. Jeremiah Brown. A.D. 1847, Jan. 3. No. 11,781.

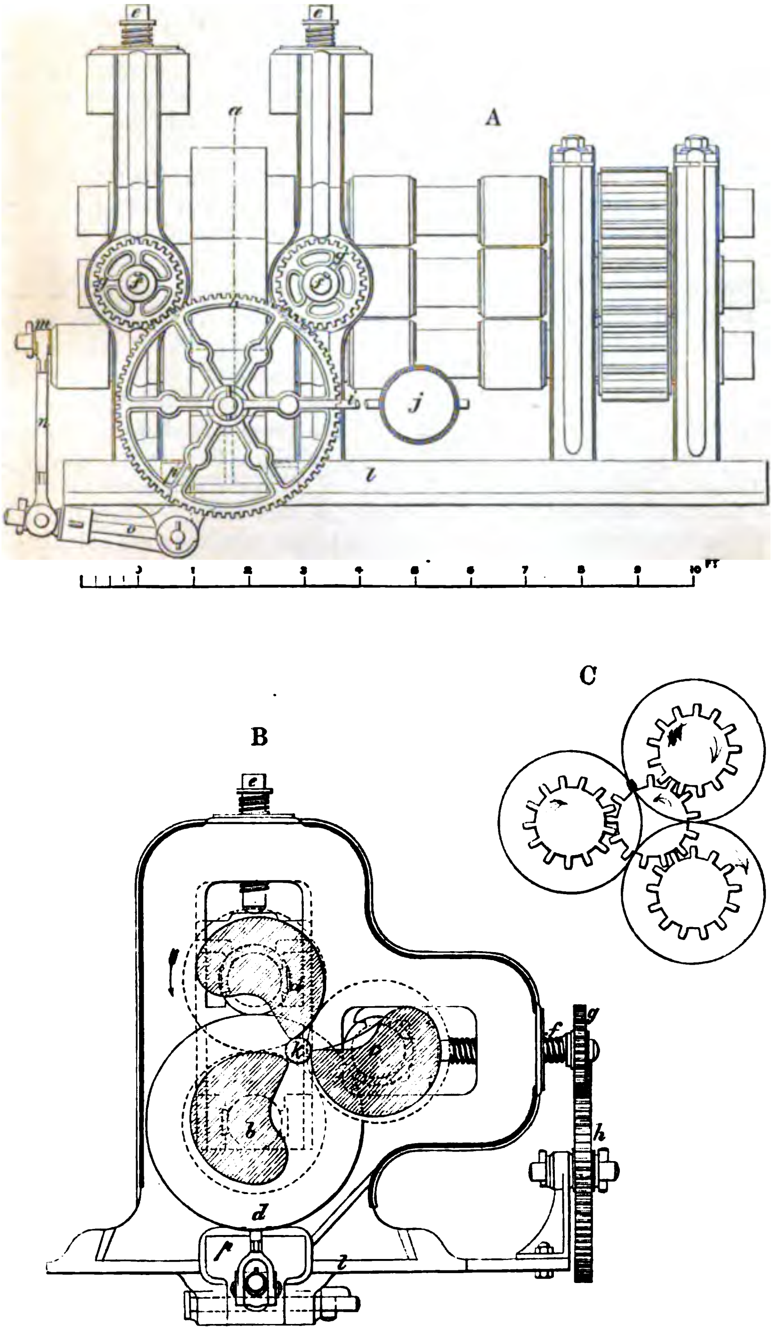


Fig. 184. Brown's Shingling Machine.

machines" of the class of squeezers.[1] I went once to see it in operation at Iron-works at Smethwick, near Birmingham, when unfortunately the spur-wheel broke immediately after the engine started, and I was disappointed. The accompanying engravings are copied from the drawings published with the specification, and from the latter the following description is extracted.

Fig. 184 A represents a side elevation of the machine; fig. 184 B represents a vertical section through the line *a*, fig. 184 A; and fig. 184 C represents an end view of the rolls and the pinions thereon, and the pinion by which the rolls are driven. This machine consists of three rolls a^1, *b*, *c*, placed in the relative situations shown in the section, fig. 184 B. The lower roll, *b*, differs from the others in having at each end an outside collar, *d*, between which collars the other rolls work; the roll *a* is capable of adjustment by the screws, *e*, *e*, and the roll *c* is capable of yielding if the ball of iron introduced be larger than is suited to the rolls. *f*, *f*, are three-threaded screws, one of which presses at each end of the axis of the roller, *c*; pinions, *g*, *g*, on these screws engage in the toothed wheel, *h*; *i* is a lever attached to the toothed wheel, *h*; *j* is a weight on this lever. When the ball of iron introduced between the rolls is larger than they are calculated to receive, the pressure of the ball on the roll, *c*, causes the screws, *f*, *f*, to retire; when, by the partial rotation of the rolls, the ball of iron is reduced in size and the pressure on the rolls is diminished; the weight, *j*, acting through the lever, *i*, and wheel, *h*, produces the rotation of the screws, *f*, *f*, and the advance of the roll, *c*. The rolls are represented in fig. 184 B in the position which they occupy when the ball of iron, *k*, has been rolled and squeezed and is about to fall from the rolls; after the ball, *k*, has fallen from the rolls, and these have performed about one-fifth part of a revolution, they are fitted to receive another ball of iron. The ball of iron falls on the bed-plate *l* of the machine, and it is then pressed endwise, or in the direction of its length, by the following mechanism:—*m* is a crank on the axis of the lower roll; this crank is connected by the rod, *n*, with the bell-crank lever, *o*, and by the operation of the crank, *m*, the ball of iron is compressed between the vertical arm, *p*, of the bell-crank lever and the bolster, *q*. It will be seen by reference to fig. 184 C, that all the rolls revolve in the same direction.

Puddling or Puddle Rolls.

For the drawings from which the accompanying engravings, figs. 185, 186, have been executed, I am indebted to the Ebbw Vale Iron Company. The term forge-train is frequently applied to a series of two pairs of rolls, by means of which the slab or bloom is converted into puddled bars. Every part of the machinery should be very strong. The rolls are of strong cast-iron, such as mottled. The first

[1] Iron, its History, Properties, and Processes of Manufacture. By William Fairbairn. 1861, p. 106.

pair, on the left, termed "roughing-down rolls," has a series of angular grooves turned on, which gradually diminish in size towards the right, and which are roughened by indentations made with a chisel. The other pair, on the right, termed "finishing rolls," has a series of flat grooves turned on, which also diminish in size towards the right. The bloom, on leaving the hammer or squeezer, and while still at a high temperature, is first passed through the largest groove of the roughing-down rolls, and afterwards in succession through the other grooves of both pairs of rolls, when at last it is extended into a long flat bar, generally pretty rough on the surface, which is designated "puddled bar," or "No. 1 iron." A copious supply of water is always required for cooling the rolls, bearings, etc., and this is conveyed through pipes suspended above, and by channels. Every time the iron has passed through the rolls, it has to be put back over the upper roll, which must entail considerable expenditure of labour and time. In order to avoid this, reversing rolls have been employed, so that immediately the iron has passed through, the motion of the rolls is reversed, and it is passed back through the next groove, etc. I have seen rolls of this kind in operation at the Blaina Iron-works.

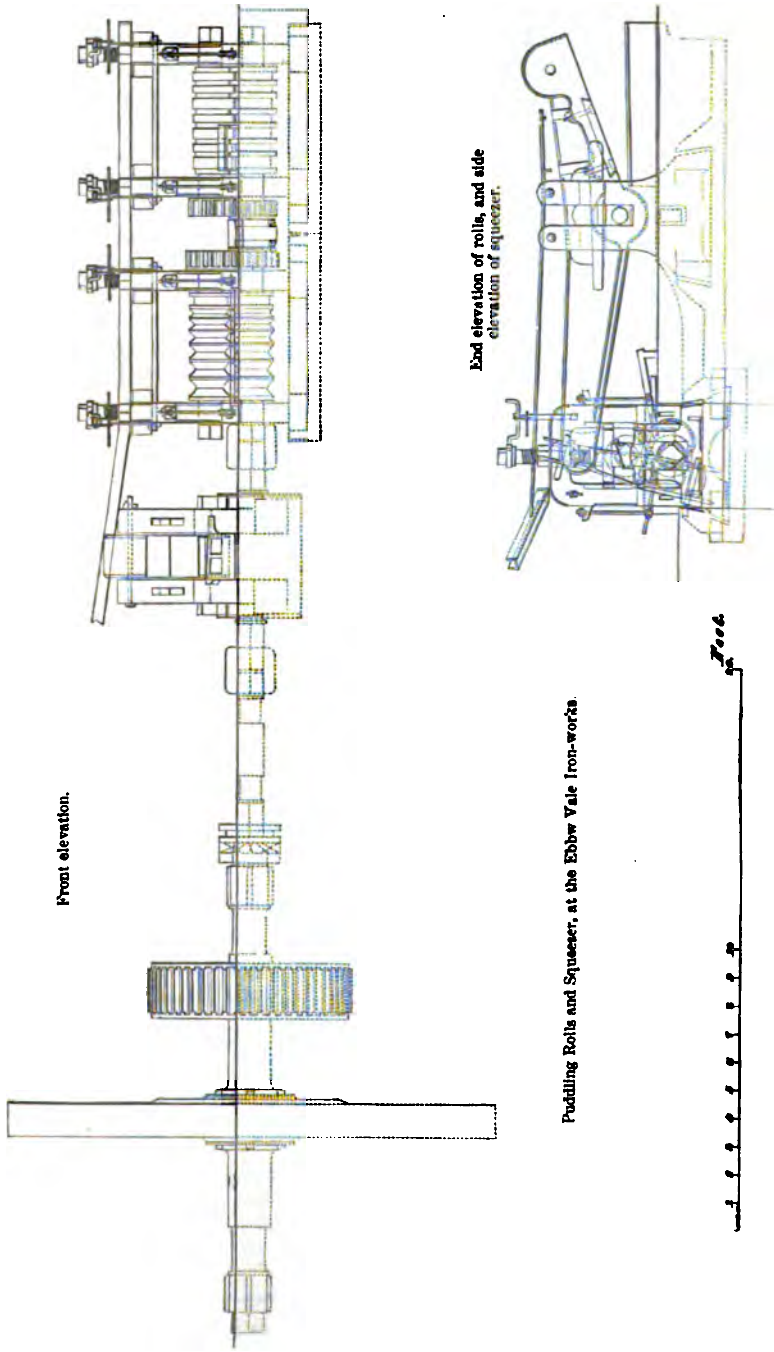
Where merchant bars and rails are made, puddled bars have generally the following dimensions: 3 in. by ¾ in., and from 15 ft. to 18 ft. in length; and 5 in. by ¾ in., and about 14 ft. in length. When intended for sheets and boiler-plates they are rolled from 6 in. to 15 in. wide; and the blooms from such bars are doubled under the hammer, and reheated before being rolled.

COMPOSITION OF PUDDLED BARS.

	I.			II.		
	a	b	c	a	b	c
Iron	97·718	97·679	97·727	98·544	98·330	98·399
Manganese	0·025			0·014		
Nickel				0·008		
Cobalt						
Copper	0·001			0·001		
Antimony	0·001			0·005		
Titanium	traces			traces		
Calcium	0·073			0·062	0·073	
Magnesium	traces			traces		
Carbon *	..			..		
Silicon	0·257	0·263		0·131		
Sulphur	0·209			0·055		
Phosphorus	0·707	0·700		0·424	0·412	
	98·991			99·244		

* Not determined.

I. Analysis by Mr. E. Riley, at the Dowlais Iron-works. "Boiled bar," *i. e.* common puddled bar made at Dowlais, and used for the centre of rails. II. Analysis by Mr. E. Riley, at the Dowlais Iron-works. Puddled bar made at Dowlais, and used for cable-bolts.



Front elevation.

End elevation of rolls, and side elevation of squeezer.

Puddling Rolls and Squeezer, at the Ebbw Vale Iron-works.

Fig. 185.

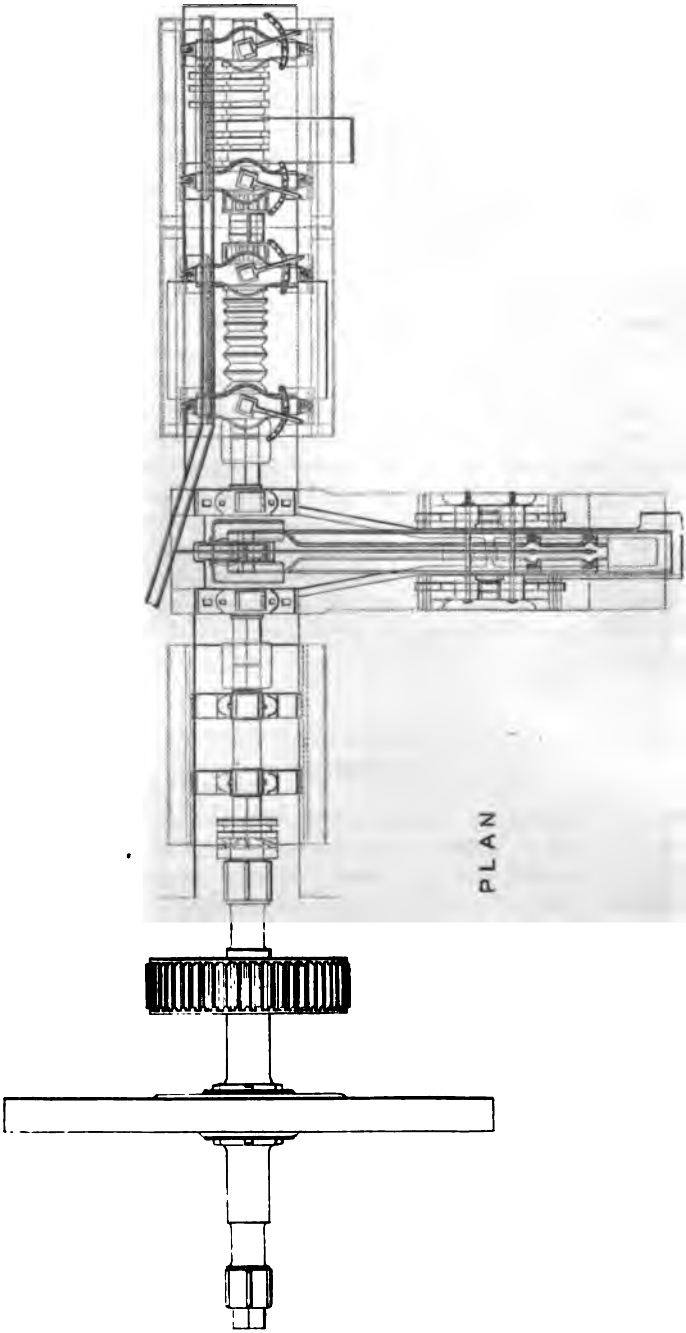


Fig 186

Desulphurization of Pig-iron in Puddling by the addition of Litharge (PbO).

Experiments on this subject have been conducted by Richter, of Leoben, at Frantschach, near Wolfsberg, in Carinthia. Pig-iron was operated on, which contained so much sulphur that the puddled bars made from it could not be rolled. In order to test the efficacy of litharge, a charge of 7 cen. (about 7 cwts.) was melted in a double puddling-furnace, with the addition of 3 lbs. of sulphide of iron, and ½ lb. of phosphide of iron. To the pig-iron when molten, 3 lbs. of litharge were added and thoroughly stirred in; when the metal boiled well, owing, it is alleged, to the combustion of the carbon by the oxygen of the litharge. The reduced lead was immediately reoxidized, a thin liquid slag, rich in oxide of lead, being formed. The oxide in this slag was again reduced, and the resulting metallic lead oxidized afresh, and so forth. In 1¼ hour from the beginning of the process, the balls were taken out, and welded into good blooms under the hammer, which without further trouble were rolled into bars. The loss was 11%, whereas usually, in the ordinary method of puddling, it amounted to 18%. A heat lasted 2¼ hours, and the balls required very careful hammering to prevent their crumbling to pieces. The iron thus produced was neither red nor cold-short.[2] On subsequent trial of litharge at Zeltweg, in Styria, less satisfactory results were obtained.[3]

WORKING OF THE PUDDLED BAR INTO MERCHANT OR FINISHED IRON.

The puddled bars are cut by shears into short pieces, varying in length according to requirements. These are piled in packets, which are raised to a welding heat, then hammered and rolled into bars; or rolled at once into bars without hammering. The operation of heating is effected in special furnaces, termed reheating, mill, or balling-furnaces, and frequently on the Continent welding-furnaces. The term balling-furnace is objectionable, as nothing resembling a ball is concerned, and it is particularly liable to be confounded with the puddling-furnace in which balls, properly so designated, are produced. Reheating-furnace is unmistakeable, and, I submit, should therefore be preferred to the other terms.

Reheating-Furnace with Coal as Fuel.

The accompanying engravings represent one of the reheating-furnaces at the Bromford Iron-works. They have been executed

[2] Jahres-Bericht. Wagner, 1861, p. 33.
[3] Berg-und Hüttenmännisches Jahrbuch. Faller. 1861, 11. p. 300.

from large working drawings expressly prepared, and carefully examined by Mr. Arkinstall, the manager. The furnace is reverberatory, and the peculiarity is that the bottom, on which the iron is heated, and which is made of sand, slopes down from one side to the other, and from the end near the fire-bridge to the flue at the opposite end, so that any liquid cinder formed may run from every part of the bottom into the flue, where it escapes through a hole left for the purpose. The construction of this furnace will be easily understood from the engravings and the accompanying short explanatory notes.

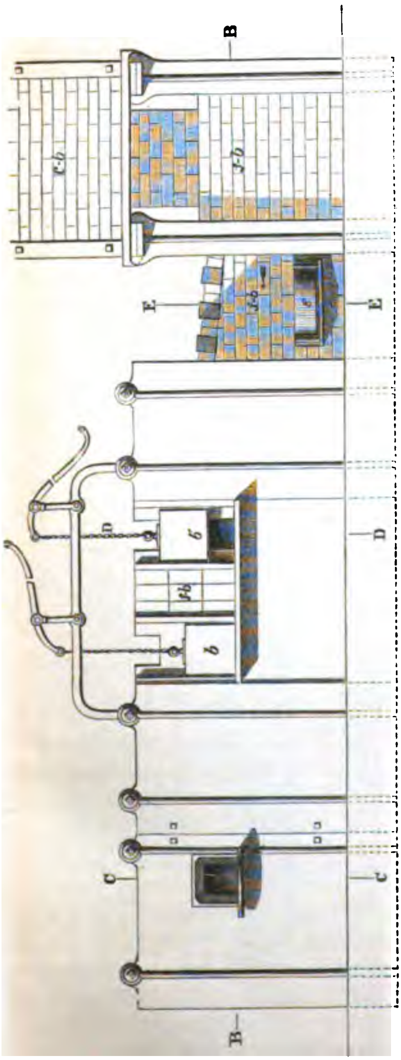


Fig. 187. Reheating-furnace, elevation on the working side.

Fig. 188. Reheating-furnace, plan of the top, with transverse section of the stack.

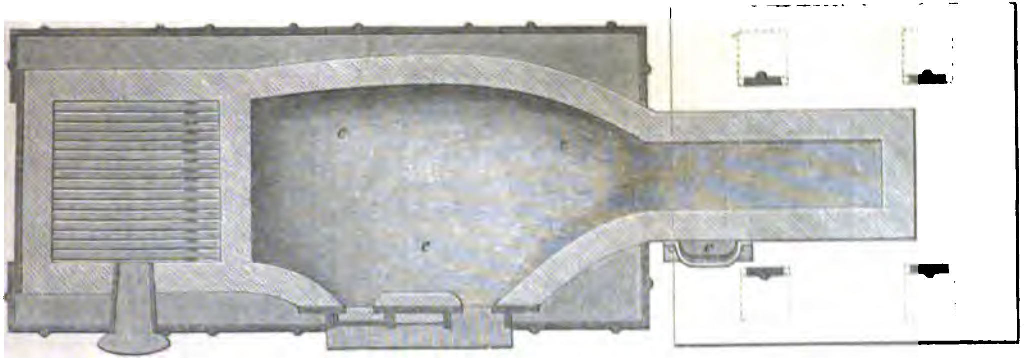


Fig. 189. Horizontal section on the line B B, fig. 187.

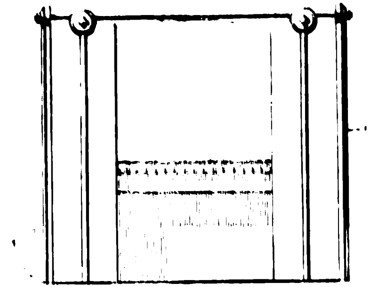


Fig. 191. End elevation at the fire-place.

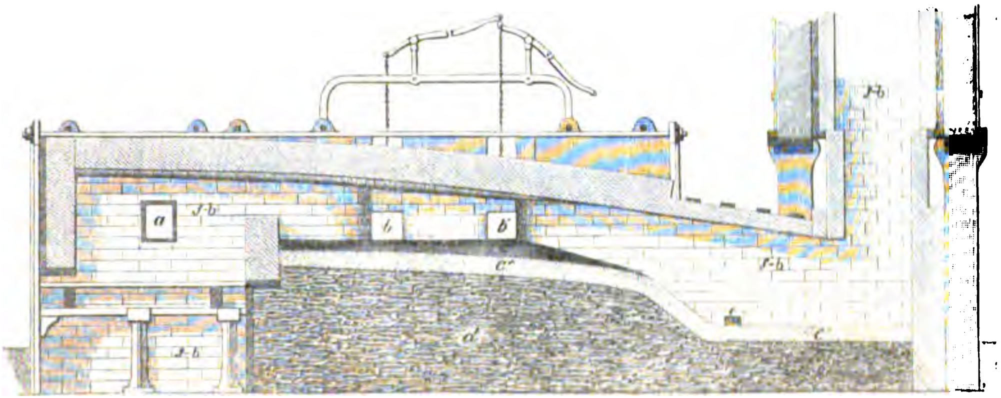


Fig. 190. Vertical section on the line A A, fig. 188. This section, however, is a section of another furnace, identical in all respects, except the parts are reversed; the working doors, etc., being on the opposite side to those in fig. 187.

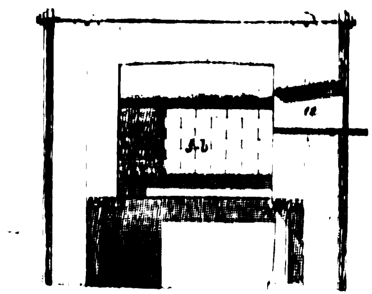


Fig. 192. Vertical section through the line C C, fig. 187.

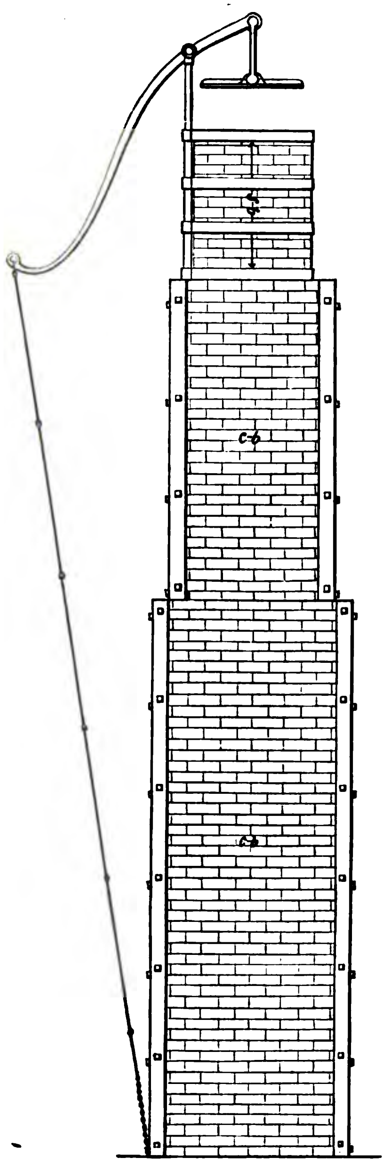


Fig. 193. End elevation of the stack, with the damper raised.

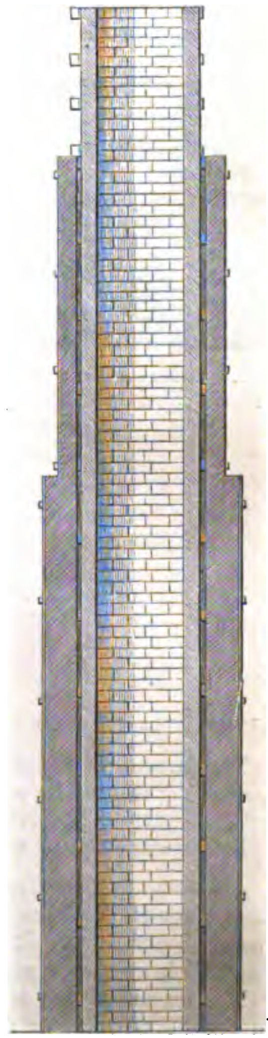


Fig. 194. Vertical section of the stack through the middle.

a, 187, 190, 192. Fire or stoke-hole.

b, *b′*, 187, 190. Working doors, through which the iron to be reheated is introduced.

c, 189, 190, 195. Sand-bottom.

c′, 190, 195. Sand-bottom, showing thickness.

d, 190, 195. Rubble work of old fire-brick, fire-brick ends, etc.

e, 187, 189, 190, 196. Hole through which the cinder flows out of the furnace. The hole itself is not actually indicated in figs. 187, 189, but only its position. In front of it on the outside is a sort of shallow fender of cast-iron, within which coal is kept burning in order to prevent the solidification of the cinder in the hole.

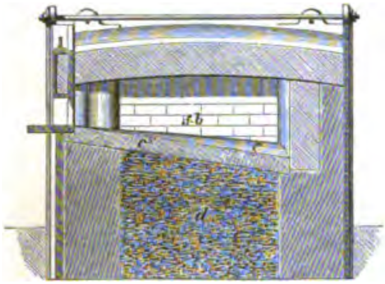


Fig. 195. Vertical section on the line D D, fig. 190.

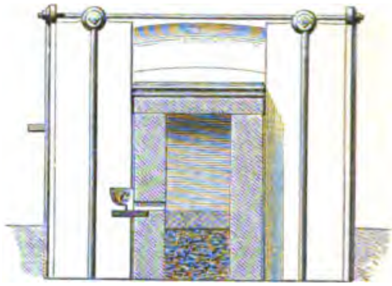


Fig. 196. Vertical section on the line E E, fig. 187.

0 5 10 15 20 FT.

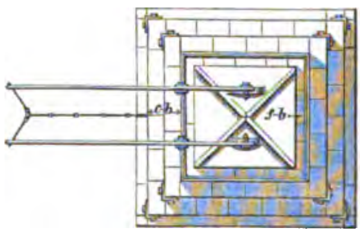


Fig. 197. Plan of the damper. The letters *c-b* indicate common brick, and the letters *f-b* fire brick.

The furnace is supported at the sides and ends by cast-iron plates, fastened at the top by wrought-iron tie-rods.

REHEATING-FURNACE WITH GASEOUS FUEL, OR GAS-WELDING FURNACE.

An account of the furnace which I have selected for illustration has been given in the First Part, and will be repeated in this, with additional observations. It was devised by Mr. Ekman, and has been successfully in operation at his iron-works in Sweden during several years.

The accompanying woodcuts have been executed from engravings in the Jern-Kontorets Annaler for 1850, which, with the exception of some differences in minor details since introduced, have been copied by Tunner in his account of the Swedish iron manufacture published in 1858.[4] Wood charcoal is the fuel employed. Fig. 198. Side elevation of the furnace.—Fig. 199. Elevation of the gas-generating chamber, which I will call the gas-chamber, on the line EF, fig. 200.

[4] Das Eisenhüttenwesen in Schweden, Freiberg, 1858.

—Fig. 200. Vertical section on the line AB, fig. 201.—Fig. 201. Horizontal section on the line KLM, fig. 200.—Fig. 203. Horizontal section of the gas-chamber on the line FG, fig. 200.—Fig. 202. Horizontal section of the gas-chamber on the line HI, fig. 200.—Fig. 204. Vertical section on the line CD, fig. 200.

The gas-chamber, *a*, is built of fire-brick, and is enclosed within a jacket of cast-iron, a free space, *f*, *f*, being left between the two. In the wall of this chamber there are two rows of twyers, *e*, *e*, *e*, etc., the upper one containing four and the lower one three. In the iron jacket is a pipe, *d*, through which cold air, at a pressure of about one inch of mercury, is introduced into the space *f*, *f*. The blast in its passage through the space *f*, *f* becomes heated to from 90° to 150° C. (Tunner). In the iron jacket opposite the twyers are small corresponding holes, *g*, *g*, *g*, etc., fitted with moveable plugs. On the top of the gas-chamber is a hopper, *b*, having a sliding bottom, *c*, *c*, through which fuel is supplied: near the bottom of the chamber are two twyers, *e′*, *e′*, one on each side. The gas-chamber communicates with the body of the furnace at the fire-bridge *m*. In the roof of the furnace, on the right of the fire-bridge, is a series of openings, *l*, *l*, etc., connected above with an iron box, *i*, having an easily moveable lid, and communicating with the free space, *f*, *f*, by two iron pipes, *k*, *k*, provided with stopcocks. By this arrangement the air entering through the pipe, *d*, passes in part into the interior of the gas-chamber, and in part into the box, *i*, from which it descends through the openings, *l*, *l*. When the gas-chamber is filled with ignited fuel, and air is injected through the pipe, *d*, carbonic oxide is copiously produced, which in its way towards the fire-bridge, *m*, is met by currents of heated air from the openings, *l*, *l*, etc., and is thereby effectually burned. In Tunner's engravings the blast, instead of being thus divided, is a continuous sheet of air; and the lower twyers, *e′*, *e′*, are omitted.

The iron is heated in the welding chamber included between the fire-bridge, *m*, and the opposite bridge, *n*, and is introduced through the doors *q*, *q*, *q*, *q*. The heat here is intense—sufficient, it is stated, to melt wrought-iron by the hundred weight. When hot-blast is used, the flame scarcely extends beyond the bridge, *n*, so complete and rapid is the combustion of the gas. Beyond the welding chamber is a second chamber, *o*, where the iron is subjected to a preliminary heating before its introduction into the former; it has two doors, *r*, *r*, at the side, and a third at the end, *t*. In the lower part of the stack, *p*, any convenient apparatus for heating the blast may be placed. In front of the doors *q*, *q*, etc., *r*, *r*, are cast-iron plates for convenience of manipulation. The tap-hole through which the cinder flows is shown at *u*.

Trial is now being made of reheating-furnaces of this kind, with coal as the fuel, at the Ebbw Vale Iron-works; and some difficulties have been met with, which may reasonably be expected to yield to perseverance. The heat of the generator is so great as to melt the ashes and form clinker, not easy to remove. The carefully-regulated injection into the generator of superheated steam in small quantity, along with the blast, may, possibly, counteract this evil, by reducing

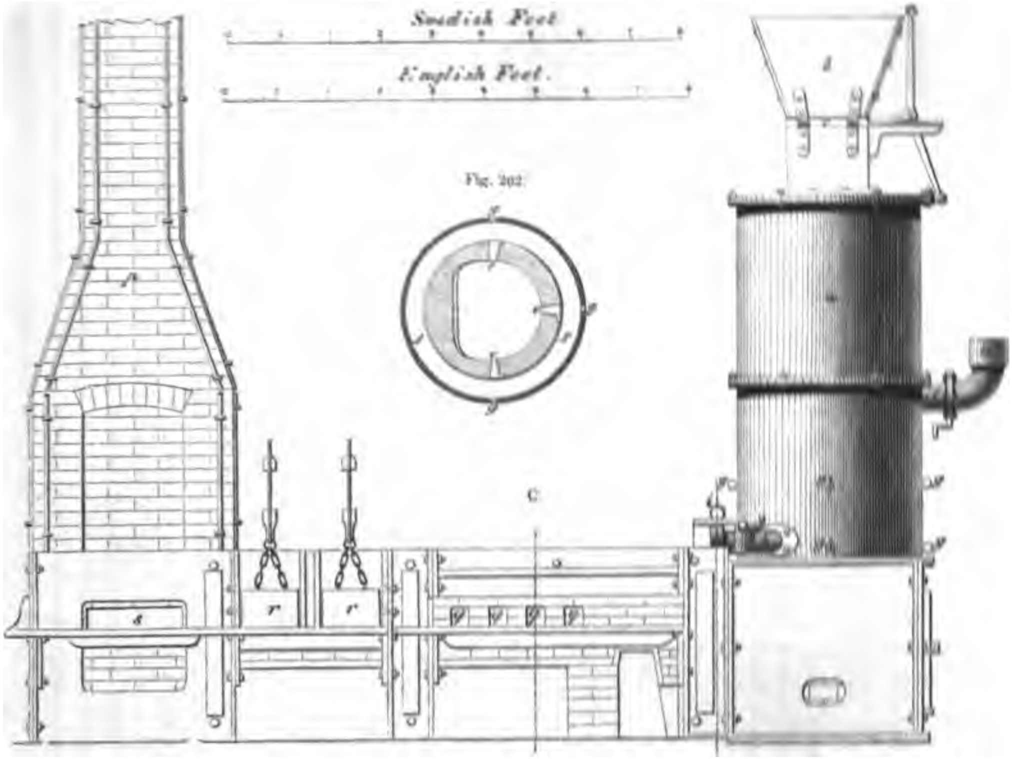


Fig. 198. Reheating-furnace with gaseous fuel. Side elevation.

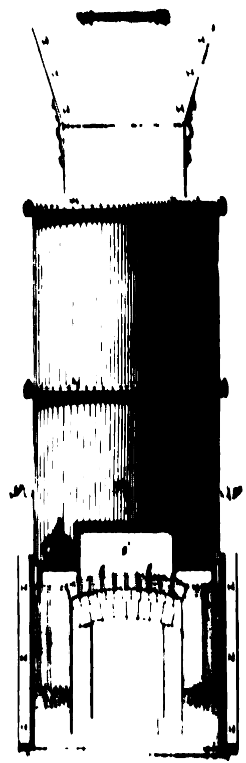


Fig. 199

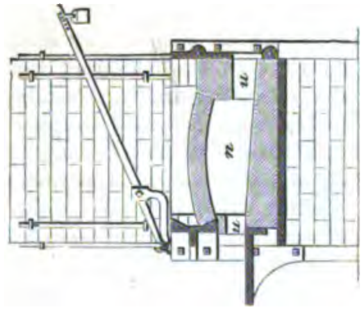


Fig. 204.

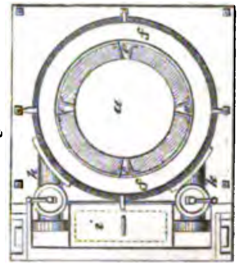


Fig. 203.

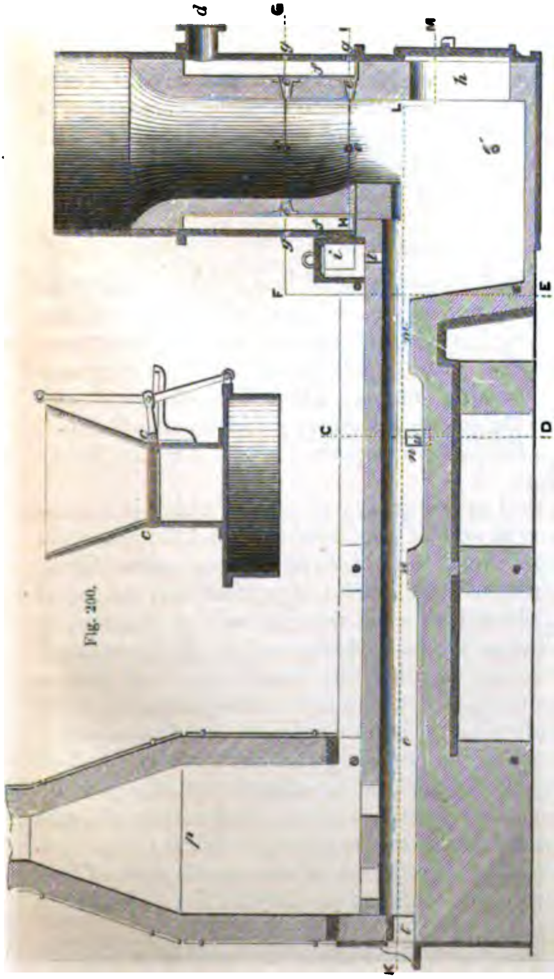


Fig. 200.

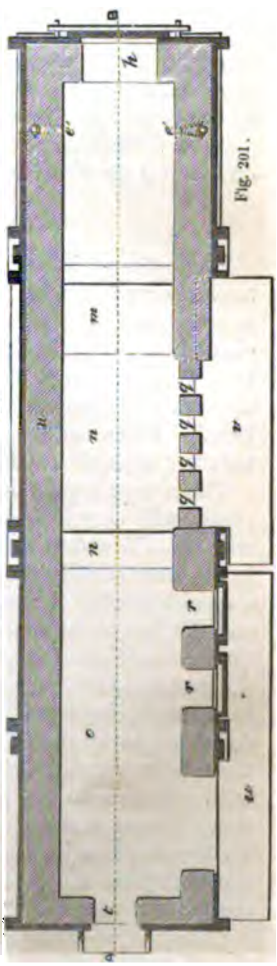


Fig. 201.

the temperature in the interior. There would not be much permanent loss of heat, because what would be temporarily abstracted by the decomposition of the steam, through the action of the incandescent carbon, would be again given out in the welding chamber by the combustion of the resulting carbonic oxide and hydrogen. A little carbonic acid, however, appears always to be generated when steam is thus decomposed, and that would occasion a permanent loss of a certain amount of heat. Caking coal, it need hardly be observed, cannot be employed, at least *per se*, in the generators of these furnaces.

One great advantage of this method of reheating is the diminution of the waste by oxidation of the iron. The pressure of the gas and air introduced should be such as to prevent the entrance of air from without through the sides, etc.; and the mixture of gas and air should be so regulated as to produce a sensibly non-oxidizing flame. Indeed, when this condition is fulfilled, the highest temperature is attained. Mr. Parry informs me that the workmen at the Ebbw Vale Works have been much struck with the small waste of iron, compared with what occurs in ordinary reheating-furnaces; and, in proof of the fact, pointed to the sharp angles which the bars, forming a pile, presented on leaving the furnace at a welding heat.

Piling.

The cut lengths of puddled bars are packed into oblong rectangular masses or piles, which, as previously stated, are raised to a welding temperature in a reheating-furnace, and then rolled out into "merchant bars," constituting what is termed "No. 2 Iron;" or they may be rolled into any other desired forms. These bars of No. 2 iron may again be treated like the puddled bars, to produce bars of "No. 3 Iron." When necessary, the pieces composing a pile are tied firmly together with thin rod-iron.

The size of a pile, as well as the quality of iron of which it is composed, will vary according to special requirements; and the same pile may contain widely different qualities of iron in different parts. Thus, in the case of rails, the interior may consist of puddled bar, the top of a special quality of iron adapted to resist wear, as well as lamination, and the foot or bottom of what is usually designated tough fibrous iron. Or the interior of a pile may be filled with small scrap iron, such as the cuttings of bolts, cut nails, etc., which have been previously freed from rust by being put into rotating barrels, when the surfaces are rendered bright by the friction of the pieces against each other. Indeed there is very great variety in the mode of constructing piles, especially with reference to the particular qualities of the iron employed; and many ironmasters maintain solemn reserve on this branch of their art. To do adequate justice to this department of the manufacture of iron would require much more space than can possibly be devoted to it in the present volume.

Cross-piling.—This expression is used when the bars in a pile are placed crosswise over each other, so that the direction of the fibres in one layer may be at right angles to that of the fibres in the next layer,

and so forth. It is conceived that a sort of interweaving, so to speak, is effected, and that greater strength is the result. In rolling plates, such as boiler plates, cross-piling is specially resorted to. I have in a former part of this volume considered the effect of rolling or other mechanical treatment upon the structure of iron, and need not here repeat what was there advanced on this subject.

Accidents in Rolling Mills.

Terrific accidents occasionally occur from the breakage of the fly-wheel, which must necessarily be heavy, and revolve at a high velocity. Several accidents of this kind have taken place within my own knowledge. In exemplification of these disastrous results I present the following report from *The Times*, Nov. 22, 1859:—

"About eleven o'clock on the night of Friday last a most destructive accident occurred at the extensive iron-works of Messrs. Gibbs Brothers, Deepfields, near Wolverhampton, by which a large iron-rolling mill was levelled with the ground, one man killed, and several others severely injured. A number of the workmen fortunately had gone to supper, and others were disengaged while some alteration was being made in the rollers, when suddenly the large driving wheel, some tons in weight, broke into fragments, which were propelled on all sides with great force. Several of the iron pillars that supported the roof, the principal iron beam, and several of the lesser ones, were broken, and the entire roof shortly afterwards came down. Of the men who were in the mill at the time, one, named John Taylor, was dug out of the *débris* insensible, and expired shortly afterwards; three others sustained severe fractures and other injuries, and two or three escaped unhurt, in a manner little short of miraculous. The whole place looks as if it had been blown up with gunpowder, and the damage is estimated at about 3000*l.*"

Examples of Yields of Puddled and Finished Iron.

The yield of merchant iron will vary, especially according to the nature of the pig-iron, the skill of the puddler, and other obvious conditions. With regard to the influence of quality, the proportion of silicon is a point of chief importance. When pig-iron containing 4%, or, as I have known, even 6% of silicon is operated on, the loss must be comparatively very great; and ironmasters who have worked such pig-iron in their refineries and puddling furnaces have been as much annoyed as puzzled to understand the cause.

South Staffordshire.—In the neighbourhood of Dudley the ordinary calculation is 24 cwts. of pig-iron to 22 cwts. of puddled bars, and 1 ton 1 cwt. 3 qrs. of pig-iron to 1 ton of puddled bars is considered good work; but with an unskilful workman, and the furnace in bad order, as much as 1 ton 4 cwts. of the same quality of pig-iron has been used to make 1 ton of puddled bars. The following returns have been communicated to me by Mr. S. H. Blackwell (Dec. 1851):—726 tons 11 cwts. 1 qr. 16 lbs. of puddled bars produced 648 tons 6 cwts. 3 qrs. 4 lbs. of finished or merchant bars, *i.e.* at the rate of 1 ton 2 cwts. 1 qr.

19 lbs. of puddled bars to 1 ton of finished bars; or 1 ton 4 cwts. 1 qr. 19 lbs. of pig-iron to 1 ton of finished bars. In a return subsequently furnished by Mr. Blackwell (July, 1859), 1 ton 5 cwts. 2 qrs. 16 lbs. of pig-iron were used in making 1 ton of finished bars. In the foregoing statements the ton of 2240 lbs. is adopted. As I have before mentioned, No. 4 grey forge-pig, *i.e.* pig-iron verging on mottled iron, is usually puddled in South Staffordshire for bars, but greyer iron for hoops, wire, rod, etc.

In estimating the cost of production of finished bars in South Staffordshire, I am informed (1859) by an ironmaster of great experience that a result, closely approximating to the truth, will be obtained by doubling the price of the pig-iron used, and adding 10*s.* per ton of bars.

South Wales.—In 1859 it was estimated that 27 cwts. of white pig-iron were required to make 1 ton of finished or merchant bars. At one large iron-work, also in 1859, about 28 cwts. of white pig-iron were required to make 1 ton of rails; and at the same establishment as much as 31 cwts. of white pig-iron had been consumed in making 1 ton of rails. At another large iron-work from 5 to 6 tons of coal were consumed in making 1 ton of rails, *i.e.* inclusive of 42 cwts. of coal used in smelting, the pig-iron being white.

Manufacture of Rails.

I do not propose to enter at length upon this important department of the manufacture of iron, which, if I err not, is destined soon to undergo great changes, from the substitution of cast-steel for malleable iron. In illustration of the machinery employed in rolling rails, I have selected that in operation at the Ebbw Vale Iron-works, to the proprietors of which I am indebted for working drawings, from which the accompanying engravings have been executed. Although these engravings are small, yet it is hoped that by careful inspection they will be found clear and instructive.

The train consists, as it will be perceived, of two pairs of rolls, with grooves turned on. In the first pair of rolls on the left the pile is gradually reduced to a solid and nearly rectangular bar; and in passing through the succession of grooves of the second pair on the right, it gradually acquires the form of the rail.

Each form of rail requires rolls specially adapted to its manufacture; and some forms cannot be produced without great difficulty and much additional expense.

A hard top, with a so-called crystalline fracture, has been considered a desideratum, in order, as far as practical, to resist wear and lamination. Iron prepared from pig-iron produced in smelting ores containing more phosphorus than usual, has been found to fulfil this condition; and as certain varieties of Northamptonshire ore are pretty rich in phosphorus, they have been expressly smelted at some iron-works in order to furnish suitable pig-iron. Iron containing a sensible amount of this element is, as we well know, cold-short; and therefore no rail, it is obvious, should consist entirely of such iron. But when

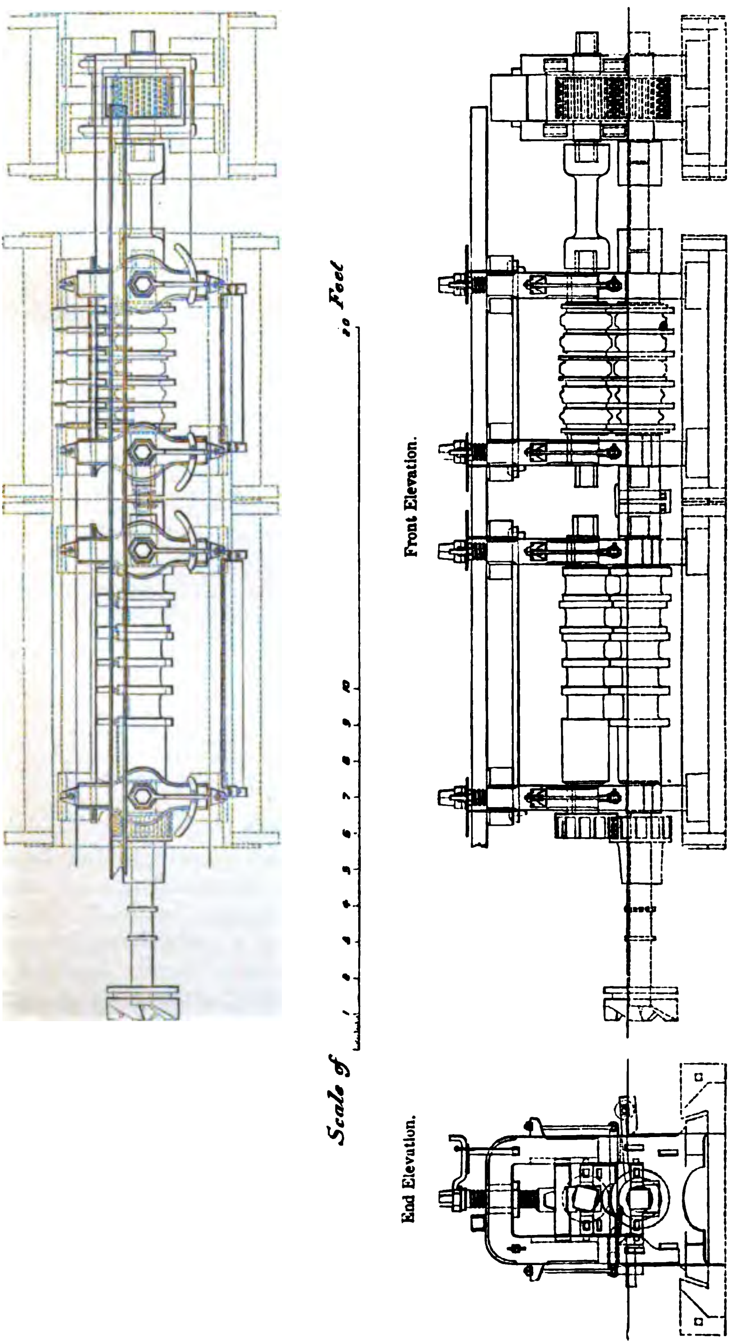


Fig. 205. Rail-Mill at the Ebbw Vale Iron-works.

applied only to the tops of rails, the case is different, owing to the strong tough iron underneath. Yet some Russian railway engineers seem to entertain a very different opinion; for, in a large contract with a certain firm, which I know well, for rails on Russian account, it was specified that the rails supplied should break when a given weight was allowed to fall upon them from a given height. I have this on the authority of my friend, the manager of that firm, a man of the highest veracity. The Russians, perhaps, prefer brittleness to lamination; or there may be other reasons, which it is not difficult to divine.

Composition of the Cinder from the Reheating-Furnace.

It is generally termed mill or balling furnace, or flue-cinder, the last appellation being suggested by its running out from the flue. It is remarkable how few trustworthy analyses of this cinder have been made, or at least published.

	I.	II.	III.
Silica	28·71	33·47	34·00
Protoxide of iron	66 01	65 83	55 36
Sesquioxide of iron	..	..	8·49
Protoxide of manganese	0·19	0·74	..
Alumina	2·47	..	..
Lime	0·81	..	0·36
Magnesia	0·27	..	traces
Sulphur	0·11	..	..
Phosphoric acid	1·22	..	..
Copper	traces	..	..
Carbon and loss	..	..	1·79
	99·79	100·04	100·00
Iron °/o	51·34	51·20	49 00

I. Analysis by Mr. E. Riley at the Dowlais Iron-works. No details are given. The composition approximates closely to the formula $3FeO, SiO^3$. II. Analysis by Dugendt in Rammelsberg's laboratory. It is described simply as welding-furnace slag from Sweden.[5] III. Analysis by Rammelsberg.[6] The slag was from a gas-welding furnace at Wasseralfingen. It had the usual colour, was largely lamellar and coated with thin crystalline plates, presenting a structure similar to that of spiegeleisen, and its specific gravity was 3·755. Estimating the sesquioxide of iron to exist in the state of magnetic oxide, Rammelsberg deduces the formula $6\,(2FeO, SiO^3) + FeO, Fe^2O^3$. But may it not have originally been tribasic silicate of protoxide, and the protoxide afterwards partially converted into sesquioxide?

The oxide of iron formed, whatever proportion of sesquioxide it may contain, must, on coming in contact with the silica of the bottom of the furnace, be converted into tribasic silicate, as the temperature is sufficiently high to decompose sesquioxide of iron under the influence of silica.

[5] Lehrbuch der chemischen Metallurgie. Rammelsberg, p. 125.
[6] Op. supra cit. p. 125.

PARTICULAR VARIETIES OF SHEET-IRON.

Tin-Plates.

Sheet-iron coated with tin or tin-plate is, as every one knows, an extensive article of commerce. There are what are termed charcoal-plates and coke plates, according as charcoal or coke is used in certain stages of the manufacture of the iron. The method of producing the bloom and slab from which charcoal plates are derived has been described; and it will be borne in mind that charcoal is only employed as fuel in effecting the conversion of the refined metal into malleable iron in the finery, the operations of refining and reheating in the hollow fire being conducted with coke as the fuel. As the further treatment of the slab involves the process of rolling, its consideration was deferred until after the general description of the ordinary machinery for rolling iron, which description has now been given. Pig-iron, which yields a somewhat red-short iron, is generally preferred for tin-plates on account of the toughness of this kind of iron while cold.

Charcoal-plates.—I shall present a summary of the whole process, as conducted at Pentwrch, Glamorganshire, for the manufacture of "best sheets RG," which stand very high in the market. For this description I am indebted to Mr. William Thomas, of Merthyr Tydvil (1860).[7] To make 1 ton of finer's bars, 23¼ tons of pig-iron are allowed, and 5¼ sacks of charcoal are consumed in the finery. The finer's bar is the lump made in the charcoal-finery, hammered and rolled out into a bar about 30 ft. long, 6 in. wide, and 1½ in. thick—often more. These bars are cut up into pieces about 1 ft. long, piled, and reheated in the hollow fire as previously described. To produce 1 ton of "finished charcoal bars," 24 cwts. of finer's bars are allowed; and about 14 cwts. of coke are consumed in the hollow fire. The proportion of coke will obviously vary with its quality, and in some works the amount consumed does not exceed 12½ cwts.

For the manufacture of tin-plates the dimensions of the finished charcoal bar vary according to the size and weight of the tin-plate, or the manner of rolling.

When the bar is finished it is taken to the rolling-mill, where it is sheared to the gauge corresponding to the description of plate required. It is then heated to redness in a reverberatory furnace, rolled, again heated, rolled, doubled, heated a third time, rolled, a second time doubled, and a fourth time heated and rolled. In some cases the heating and rolling are conducted six times. The length of the bar exceeds by about 1 in. the width of the sheet to be made, so as to allow for the shearing process, and the bar is therefore rolled with its axis parallel to that of the rolls. Great attention is necessary in the construction and management of the mill furnaces, so that the heating of

[7] I have incorporated some additional details, taken from a description of the process, as conducted at the Pontypool Tin-plate Works, which I received in 1853 from Mr. Kenyon Blackwell, formerly one of the proprietors and the manager, and also from other sources.

the bar and sheet iron for rolling may be effected with the utmost regularity, and without the formation of scale on the surface of the bars or sheets; for when scaling takes place, from the draught in the furnace being too keen, or the heat raised too high, the quality of the iron is injured. The scale, if subsequently rolled into the iron, leaves a rough surface on the plates when it is separated in the after process of "pickling." The sheets are sheared to gauge, and afterwards split or separated, and the process is termed "opening." Before tinning they are termed "black-plates." Plates on which a minimum of tin is to be used are rolled heavier, and consequently require more iron, than those which are to be well coated. The yield of "black-plate" is from 80% to 90% of the iron used, the minimum yield being obtained from narrow plates rolled in one length and doubled three times, thus making 8 sheets of 14 in. × 10 in. size; or doubled three times and rolled in two lengths, making 16 sheets of 14 in. × 10 in. The maximum yield is from wide plates doubled only once, making 4 sheets, rolled in two lengths. The usual method of proceeding for plates which are not very thick—such as 1X (the trade mark) of 14 in. × 10 in. or 14 in. × 20 in., and 1XX of 14 in. × 10 in. and 14 in. × 20 in.—is to use pieces of iron sufficiently heavy for 16 sheets of 14 in. × 10 in. size, or 8 sheets of 14 in. × 20 in. size; and the method of arriving at the weight is as follows:—Say for 1X of 14 in. × 20 in. (charcoal) 112 sheets per box.

	cwt.	qr.	lbs.
Weight when tinned................................	1	1	0
Shearhouse weight	1	0	23

The yield of "black-plate" in this variety would be 87%.

$$\text{Then } \overset{\text{cwt.}}{1} \quad \overset{\text{qrs.}}{0} \quad \overset{\text{lbs.}}{23}, \text{ or } \frac{\overset{\text{lbs.}}{135}}{0\cdot 87} = \overset{\text{lbs.}}{155},$$

which is the weight of iron required for 1 box of plates. And as each piece of iron is to make 8 sheets, 14 pieces would be necessary for 112 sheets. Therefore, $\frac{155}{14} = 11$ lbs., which is the weight of one piece to produce 8 sheets in 2 lengths doubled twice.

The above formula will apply to a box of any weight of the same dimensions rolled in the same manner. It should be observed that the oftener a plate is doubled the greater will be the waste, owing to the larger amount of shavings cut off from the extremities.

The plates are now "pickled," *i. e.* they are immersed in heated dilute hydrochloric or sulphuric acid, consisting of about 16 parts, by measure, of water to 1 of acid. The use of sulphuric acid made from iron-pyrites, and, therefore, likely to contain arsenic, is carefully avoided in tin-plate works. The acid is contained in leaden troughs set over small grates, and the plates are put in edgewise, and kept slightly in motion until the whole of the scale has been detached and dissolved. The outside plates, which are more oxidized by exposure in the mill furnace than those in the middle (when 4 or more sheets

are rolled together), are separated from the others in order to be pickled by themselves, as they require relatively a longer immersion in the acid. After this they are taken out, washed in 2 or 3 waters, and drained on a stand. They are next subjected to a bright red heat, during from 12 to 24 hours, in closed cast-iron "annealing boxes" or "pots," in a reverberatory furnace. The lids of these boxes are made tight by being covered to the depth of 2 in. or 3 in. with sand or burnt oxide scale, which accumulates from this process in the annealing-house. The heat to which the plates are thus subjected is kept as high as it can be without softening them to such a degree as to cause them to stick so fast together as to prevent their separation when cold. The door of the annealing-furnace is on a level with the floor, and the pots are wheeled in on a railway. The plates, which are expected to be free from scale, are next passed cold and singly through 3 pairs of cold-chilled rolls, highly polished with emery and oil. The rolls must be set true and accurately adjusted, in order to give the plates a perfectly flat set and a well-polished surface, as such a surface saves tin, and is essential to a good appearance of the finished plate. After having been thus cold-rolled, they are again annealed or softened at a lower temperature than in the first annealing (as their surfaces would be damaged by being in any degree stuck together), dipped in sulphuric acid, rather more diluted than previously, and placed in cast-iron troughs containing clean water, and renewed by a stream flowing constantly through. After remaining a short time in the first water, the plates are carried forward to other troughs to be examined singly, and scoured, if necessary, with sand and hempen pads before they are delivered to the tinman. Each of the scourers, of whom there is one to each tinman or set of "tin-pots," has two troughs, one to receive the plates as they come forward, and the other to receive every plate, one by one, as the scourer singles them over and examines them on both sides, to remove with a wad and sand every spot and stain of acid or trace of scale, in order that the plates may go perfectly clean and bright into the hands of the tinman.

The "tinman" (who is the foreman of the set employed to tin the plates, comprising a "wash-man," "grease-boy," and "list-boy") receives the plates from the scourer, and places them in a bosh of water near him, until he is ready to remove them to the grease-pot.

The plates are taken from the trough, and put singly into the "tinman's pot," which is full of melted grease; and they are left there until they are completely coated with grease. The grease by use becomes "sticky." Fresh grease is not suitable, and, according to Mr. Williams, drives off the water from the plates mechanically, as they are immersed in it one by one. The temperature of this pot is very low, and little evaporation of water takes place, except when it accumulates on the surface. The grease is never wholly free from water. The "grease-pot" and the other pots to be mentioned in the sequel are of cast-iron, and set in brickwork over fire-grates. They are arranged in a row before a side light; and in tin-plate works which I have visited the manipulation takes place from right to

left.[a] The plates are next plunged in parcels into the "tin-pot," containing a bath of molten tin covered with grease. The block-tin employed is kept melted before use, with sticks of wood immersed, whereby it is freed from certain impurities which are skimmed off. The effect of this treatment will hereafter be fully explained in another volume. From this they pass in parcels into the "wash-pot," which is divided into two compartments, one larger than the other. This pot is likewise filled with molten tin covered with grease. They are first put into the larger compartment; and as this pot contains tin of better quality than the "tin-pot," and as its temperature is comparatively low, the plates can be kept in it without becoming "dry" until the wash-man is prepared to brush them. The temperature is, however, high enough to perfect the tinning process, in case it should not have been properly performed in the "tin-pot." In the subsequent operations the plates are treated singly. The plates are withdrawn, placed on a table, and wiped on both sides with a brush of hemp. Then, in order to obliterate the marks left by the brush, and give a polish to the surface, the plates are dipped in the second or smaller compartment of the "wash-pot." This compartment always contains the purest tin; and as the latter becomes alloyed with iron, it is transferred first to the larger compartment and afterwards to the "tin-pot." The plates are now removed to the "grease-pot," which is filled with a molten mixture of equal parts of Russian tallow and palm oil, or with palm oil alone, and which requires skilful management as to temperature. The object is to allow any superfluous tin to run off, and the quantity so removed is two or three times greater than what is retained on the plate. Care must be taken to keep the grease hot enough for the purpose, but not so hot as to cause oxidation when the plates are withdrawn and exposed to the air. The length of time during which the tin-plates remain in the "grease-pot" determines, with great exactness, the quantity of tin to be left on them, as the contact of the molten grease keeps the tin liquid, and allows it to run off the plates from the vertical position in which they stand in the pot. The plates next go into the "cold pot," and are left exposed to the air to cool. As the excess of tin drains off a plate, an accumulation or "wire" of tin is left at the lower edge. This "wire" is removed in the "list-pot," which is a small pot containing a layer of molten tin about ¼ in. deep, and kept at a temperature sensibly beyond the melting-point of tin. The lower edges of the plates are dipped

[a] In the First Part I mentioned the fact of a dark-grey powder accumulating in the grease-pot, which was formerly thrown away, in ignorance of its nature. It consists for the most part of finely-divided metallic tin; and one specimen, which I brought away from the Pont-y-Mister Works, near Newport, contains 60 % of tin. Mr. Williams, of the Morfa Tin-Plate Works, informs me that there should be no accumulation in the grease-pot of anything but the molten tin which trickles from the plates. "The grey powder," he says, "must have been obtained elsewhere." However, I myself took the specimen of this powder from the grease-pot; and there appears to me to be no difficulty in accounting for its formation. It consisted for the most part of finely divided metallic tin, and, no doubt, was produced just in the same way as the finely divided mercury in blue-pill, namely, by friction with grease.

in the "list-pot," and left until the tin forming the "wire" is perfectly fused, when on raising the plates, always singly, and giving them a quick blow on the surface with a stick, the excess of tin is detached. The plates are now carefully cleaned by working each plate edgewise in troughs filled with bran in which some meal has been left; they are finally rubbed with flannel, and then taken to the assorting room, where each plate is separately examined, classed, and packed in boxes for the market.

The tests of quality in tin-plates are ductility, strength, and colour; and in order to obtain this combination of qualities in the highest degree, the iron employed must be of the best description, and the manufacture conducted with proportionate skill. In referring to tin-plates, the standard of quotation is always taken at 1 C (Common No. 1). This is a box containing 225 plates, which should weigh exactly 112 lbs., but 3 lbs. under or over are tolerated.

About 8 or 8½ lbs. of tin are used on an average per box of tin-plates. The quantity of mixed metal for terne-plates will vary from 10 lbs. to 14 lbs., according to the proportions of lead employed.

Coke-plates.—In the manufacture of these plates the puddling-furnace is substituted for the charcoal-finery. At Pentwrch 23½ cwts. of crude pig-iron are allowed for 1 ton of puddled bars, and 23 cwts. of puddled bars for 1 ton of finished bars (No. 2 iron). The pig-iron is refined, and the charge for puddling, in one of the double puddling-furnaces here used, is from 7½ cwts. to 8½ cwts. One refinery supplies one double puddling-furnace, which yields about 36 tons of puddled bars per week. The consumption of coal is 15 cwts. for 1 ton of puddled bars (No. 1 iron). In producing 1 ton of finished bars (No. 2 iron) from the puddled bars, 21 cwts. of coal are consumed. The wages paid for refining are 2*s.* 10*d.* per ton, and for puddling 5*s.* 6*d.* (Aug. 1860). The puddled bars are cut into lengths, piled, heated in a mill-furnace, and hammered into slabs. The slabs are heated in what is termed a "wash-heat," and rolled into finished bars, which are rolled into sheets. The hammering is sometimes omitted, and in that case the pile is roughed down, reheated, and finished in the bar-rolls.

The variety of tin-plates called "terne-plates" are coated with an alloy of tin and lead, containing from ⅓ to ⅔ of lead; and coke-plates as well as charcoal-plates are used in their manufacture. In most first-class works "terne-plates" are made from the latter, the former being only exceptionally used. Their surface is dull, compared with that of tin-plates. They are largely exported to Canada, and there used for roofing.

Not very long ago I had the opportunity of observing in tin-plates from a certain establishment, a defect which made its appearance a short time after their manufacture. The whole surface became more or less freckled with minute, greyish-black, dull, protuberant spots. At the time I was only able to make an incomplete examination, and could not satisfy myself as to their nature, much less as to their cause. It is therefore almost vain to hazard a conjecture on the subject. However, I conceived that possibly there might have been something unusual

in the process of pickling, or in the surface of the plates previously to tinning. In the first part I have described a curious defect in brass which appears some time after the processes of dipping and lacquering, and which may have some analogy with the defect in question. Both hydrochloric and sulphuric acids are now-a-days frequently contaminated with arsenious acid, and the effect of this might be the deposition of metallic arsenic upon the plates pickled in acids thus impure. But whether arsenic so deposited might in any way have contributed to produce the spots, I do not know, though I should think not.

Belgian Sheets.

The Belgians have justly acquired a high reputation for the manufacture of large thin sheets of iron, having a fine, smooth, glossy, bluish-black surface. In the International Exhibition, 1862, several firms showed really magnificent samples of such sheets. The character of the surface is evidently due to a thin and firmly adherent coating of oxide of iron; for on bending the corners of some of these sheets backwards and forwards, the coating was detached, leaving underneath a white metallic surface of iron. The glossiness must, I should suppose, have been produced by rolling after the formation of the coat of oxide, notwithstanding the sheets had been subsequently annealed, as proved by the absence of rigidity; but I am not acquainted with the details of the manufacture.

Russian Sheets.

The Russians are renowned for a particular description of sheet-iron, which they alone have as yet been able to produce. Sheets of this iron have a remarkably smooth, blacker, and more glossy surface than the Belgian sheets; and on bending them backwards and forwards repeatedly, I have never succeeded in separating any coating of oxide. They possess great tenacity. The method of their manufacture is, I believe, kept rigidly secret. They are made from iron smelted and worked throughout with charcoal as the fuel. I am informed that at the last stage, after the completion of the rolling, they are hammered in packets, with charcoal dust interposed between them, and afterwards assorted, the outer sheets being inferior in quality, and put aside accordingly. The manufacture of such sheets is a desideratum in this country, and tin-plate makers have assured me that the man who first succeeds in the attempt may expect ample remuneration. The character of the surface seems to diminish the tendency to rust. I may state that I have received the foregoing information respecting the Russian plates from three independent sources.

SLIT RODS.

These rods, which are square or rectangular in section, are formed by the slitting-mill, which consists essentially of a pair of rolls having a series of narrow sharp-edged parallel collars, with the intermediate depressions or grooves of the same width. The collars and grooves are produced in the lathe; and the former work between the latter, leaving spaces sufficient for the rods to pass through. There is

a curious point of interest connected with the history of the slitting, or, as it is sometimes called, the splitting mill, as will appear by the following extract from the writings of Coleridge, inserted by Scrivenor in the first edition of his History of the Iron Trade.[9]

"The most extraordinary and the best attested instance of enthusiasm existing in conjunction with perseverance, is related of the founder of the Foley family. This man, who was a fiddler, living near Stourbridge, was often witness of the immense labour and loss of time caused by dividing the rods of iron necessary in the process of making nails. The discovery of the process called splitting, in works called splitting-mills, was first made in Sweden, and the consequences of this advance in art were most disastrous to the manufacturers of iron about Stourbridge. Foley, the fiddler, was shortly missed from his accustomed rounds, and was not again seen for many years. He had mentally resolved to ascertain by what means the process of splitting bars of iron was accomplished; and, without communicating his intention to a single human being, he proceeded to Hull, and thence, without funds, worked his passage to the Swedish iron port. Arrived in Sweden, he begged and fiddled his way to the iron foundries, where, after a long time, he became a universal favourite with the workmen; and, from the apparent entire absence of intelligence, or anything like ultimate object, he was received into the works, to every part of which he had access. He took the advantage thus offered, and having stored his memory with observations and all the combinations, he disappeared from amongst his kind friends as he had appeared—no one knew whence or whither. On his return to England he communicated his voyage and its results to Mr. Knight and another person in the neighbourhood, with whom he was associated, and by whom the necessary buildings were erected and machinery provided. When at length everything was prepared, it was found that the machinery would not act; at all events, it did not answer the sole end of its erection—it would not split the bar of iron. Foley disappeared again, and it was concluded that shame and mortification at his failure had driven him away for ever. Not so: again, though somewhat more speedily, he found his way to the Swedish iron-works, where he was received most joyfully, and, to make sure of their fiddler, he was lodged in the splitting-mill itself. Here was the very end and aim of his life attained beyond his utmost hope. He examined the works, and very soon discovered the cause of his failure. He now made drawings, or rude tracings; and having abided an ample time to verify his observations, and to impress them clearly and vividly on his mind, he made his way to the port, and once more returned to England. This time he was completely successful, and, by the results of his experience, enriched himself and greatly benefited his countrymen. This I hold to be the most extraordinary instance of credible devotion in modern times."

[9] Letters, Conversations, and Recollections of S. T. Coleridge, Esq. A comprehensive History of the Iron Trade throughout the World, from the earliest Records to the present Time. By Harry Scrivenor, Blaenavon. London, 1841, 8vo. p. 120.

For the following additional particulars I am indebted to Mr. John Bagnall, of Charlemont Hall, near West Bromwich, who has devoted great attention to the history of the Iron Trade:—"The founder of the Foley family was Richard Foley, of Stourbridge, who raised a large fortune by being concerned in the Iron-works there. He died July, 1657, at the age of 80. Sir Simon Degge says, 'Richard Foley was first a seller of nails, afterwards a forgemaster, and a very honest man in Stourbridge.' Richard Foley, of Stourbridge, founded a school at Dudley for 50 boys, anno 1634. It was endowed with some lands, which Mr. Foley recovered after they had been some time alienated from the original charitable bequest of the person who left them. To this he added something of his own, and built a convenient school-house. Richard Baxter was the first master."[1]

Swedenborg has given a large engraving of a Swedish slitting-mill, and mentioned the existence of similar machines both in Germany and England.[2] But I cannot find that he has made the slightest allusion to Foley. I have interrogated Mr. Grill, Mr. G. Ekman, and Mr. Styffe, of Stockholm, about this story; but they had not even heard of it previously, although no men, I believe, are better acquainted with the history of the Swedish Iron Trade. They have undertaken to make every enquiry relating to the subject.

It is stated that Godfrey Box of Liége erected at Dartford, in 1590, the first iron-mill for slitting bars.[3]

SPECIAL QUALITIES OF IRON.

South Yorkshire.

Of all iron produced in Great Britain, none has acquired so high a reputation for special purposes as that manufactured by the Lowmoor Iron Company, the Bowling Iron Company, and some other firms in the same vicinity. It is extensively applied as the material for engines and machines of various kinds, for boiler plates and railway tyres, etc., in which great strength and metal of thoroughly trustworthy quality are essential. So universal is the recognition of the high character of Lowmoor iron, for example, that when Civil Engineers specify that it shall be used in cases where security to life is the first consideration, they are absolved from responsibility in the event of the occurrence of accidents from breakage of machinery. There are several firms in Yorkshire which produce iron equal in quality to that of Lowmoor, and of these may be particularly mentioned the Bowling and the Farnley Companies. The Lowmoor and Bowling Companies, on account of their long established reputation, generally obtain from *4l.* to *6l.* per ton more for their iron

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[1] Nash's Worcestershire, 1. p. 360, and 2. p. 464.

[2] De Ferro, 1734, p. 253. "Angliæ sunt etiam plures machinæ, quibus ferrum secundum longitudinem suam attenuatur, et in partes, contos et cingula, quibus cadi circumligantur, *secatur* et diducitur."

[3] Scrivenor, History of the Iron Trade, new edition, 1854, p. 36. The authority cited is *Gough's Camden*. The story of Foley seems hardly compatible with this statement; and in the new edition of his work Scrivenor has omitted the story.

than the other companies; and it is reported that they never undersell each other. I believe that all the iron made by these firms is manufactured in essentially the same manner, and with equal care.

I am indebted to Messrs. Armitage for the following description of the process of manufacture in operation at the Farnley Iron-works. The pig-iron is refined, and the refined metal is broken in pieces of various sizes, from about 6 in. to 15 in. square. These are puddled in heats of 2½ cwts. (long weight). The puddler works up 9 heats, or 22½ cwts., in a turn of 11 hours. The furnace is comparatively small, and has a second bed, at a higher level than the puddling bed, heated by the waste flame from the latter in its course to the stack. The charge is put into the upper bed, and when red-hot is transferred to the lower bed, where it is puddled with the addition of hammer-slag, and worked in the usual manner into 2 or 3 balls, as may be required. The balls are hammered under a 7-ton helve into rough plates, called "stampings," about 12 in. square and 1½ in. thick. The stampings are broken under a "guillotine hammer" into pieces varying from about 2 in. to 4 in. square. These pieces are examined, and carefully assorted according to the different purposes for which the iron is needed. Stampings are chiefly used for railway tyres and bar-iron. The broken up stampings are piled on thin wooden boards into small heaps, called "balls," which are raised to a welding heat in a mill furnace and worked into oblong rectangular blooms under a Nasmyth's hammer. The bloom is reheated and hammered three times until perfectly sound, when it is afterwards drawn out into any form required.

Farnley iron is principally employed for locomotive tyre-bars, in which case the bloom is hammered into the form of a rectangular slab. It is then reheated in a mill furnace and rolled into a tyre-bar, which is sawn to the proper length and bent into a hoop. All these processes are effected in the same heat.

Boiler-plate is not generally made from stampings, but from "lumps," about 12 in. square and 4 in. or 5 in. thick, formed by hammering out the puddled balls. The lumps are piled together, according to the dimensions of the plate required. They pass 4 times into the mill furnace, and under the hammer, until they become perfectly welded together and sound. They are then drawn into a "slab," varying in size according to circumstances, from about 2 ft. to 4 ft. long, and from 12 in. to 20 in. broad. These slabs are heated in a mill furnace, and rolled into plates, which, when cold, are sheared square agreeably to order. Round, square, and flat bars are all hammered in the same manner as the tyre-bars, and planished under case-hardened tools. All the iron manufactured at the Farnley Works is only rolled once.

There was an admirable collection of Farnley iron at the International Exhibition of 1862. Nothing could be more beautiful than the fracture of the tyre-bars, which was bright, fine-grained, uniform, even, clean, and sound. Tyres also from the other Yorkshire firms presented the same qualities with respect to fracture. The boiler-plate exhibited by the Lowmoor Company was of the best quality,

[illegible]

The Lowmoor Company have blast-furnaces of their own. They work several beds of coal and the accompanying beds of ironstone. There is the "Black Bed Coal" which occurs at from 4[illegible] to 42 yards above their renowned "Better Bed Coal." The former is from 34 in. to [illegible] in. thick, and is used for steam-engine boilers, etc.; and the coke from it is burnt in lime-kilns, stoves for drying cores, and other purposes, where superior quality is not needed. The latter never exceeds 2[illegible] in. in thickness, and in some localities in the vicinity is only 1[illegible] in. thick, yet is nevertheless raised. The ironstones are the "Black Ironstone" and the "White Ironstone." The "Black" lies immediately above the "Black Bed Coal," and occurs in 6 strata, forming together a bed 5 ft. thick: its average yield is stated to be about 28 % of iron. The "White" lies 22 yards above the "Black Bed Coal," and occurs in 7 strata, forming a bed 7 ft. thick: its average yield is also stated to be 28 % of iron, but it is not so highly esteemed as the "Black."[*]

The superiority of the Lowmoor iron cannot, I believe, be ascribed to the ores from which it is made, because there are ironstones in South Staffordshire and elsewhere, which in respect of freedom from the two pre-eminently noxious ingredients, sulphur and phosphorus, are quite equal to the best of Lowmoor. It is pretended that the "Better Bed Coal" is the principal cause of that superiority on account of its comparative freedom from sulphur. An average sample of carefully selected specimens of this coal has been examined in my laboratory by Mr. C. Tookey, and found to contain 0·35 % of sulphur, which is about 0·15 % less than in the best Staffordshire "Thick-coal." That it is an excellent coal in every respect for the purposes to which it is applied there can be no doubt; but how far such a thin

* These details are from a MS. catalogue of specimens presented by the Lowmoor Company to the Museum of Practical Geology.

bed,—which, however skilfully worked, cannot yield more than 1700 tons to the acre,—would suffice for such a vast establishment as that of Lowmoor, ironmasters may judge for themselves. I have it on indisputable authority that it does not suffice. Hence the conclusion that Lowmoor iron owes its deservedly high reputation to the special mode of manufacture, and the care with which every manipulation is conducted. This is more creditable to the Lowmoor Company than mere excellence resulting from the superior quality of the iron-producing materials employed.

The following analysis of the iron of an experimental armour-plate manufactured by the Lowmoor Company has been made in my laboratory by Mr. C. Tookey.

Carbon	0·016
Silicon	0·122
Manganese	0·280
Nickel	distinct traces
Cobalt	do. do.
Sulphur	0·104
Phosphorus	0·106
Iron, by difference	99·372
	100·000

The specific gravity of this iron was 7·8083, and the tensile strength 24·644 tons to the square inch: these results were obtained by my friend Mr. Fairbairn.

South Staffordshire.

South Staffordshire has acquired a high reputation for the so-called fibrous iron, which is tough, comparatively soft, and neither red- nor cold-short in a sensible degree. But owing to competition, the introduction of bad ores, or one cause or other, inferior qualities of iron have of late been manufactured in this district, which has thereby suffered in character; and in this respect South Staffordshire is by no means singular. This county has ores and fuel capable of producing thoroughly good iron; but cannot compete successfully with certain other districts, which have the means of producing cheaper iron of inferior quality. Some ironmasters are ambitious with respect to "great makes," and others with respect to "high quality;" and those of the latter class seem to have best maintained their ground in the periodical depressions affecting the iron trade. It deserves to be permanently recorded, that the Earl of Dudley's magnificent collection in the International Exhibition, 1862, illustrative of the iron manufacture in South Staffordshire, was the only one which worthily sustained, I may say vindicated, the reputation of this country in the estimation of the world. To the Earl's agent, Mr. Richard Smith, the merit of that collection was wholly due.

Carbon	0·190
Silicon	0·144
Sulphur	0·165
Phosphorus	0·140
Iron	99 361
	100·000

By Mr. Henry for Mr. S. H. Blackwell. Boiler-plate made from No. 4 grey pig-iron, smelted at Russell's Hall, near Dudley, from the following mixture of ores: Froghall red hæmatite 10 cwts., Forest of Dean brown hæmatite 2 cwts., Ulverstone red hæmatite 7 cwts., Whitestone and Gubbin (South Staffordshire) together, roasted, 10 cwts., Red mine (North Staffordshire) roasted, 1 cwt.

Swedish Iron.

This world-renowned iron has already been referred to several times. It is in special request at Sheffield for the manufacture of steel of the highest quality. There are several varieties of it, which are distinguished by particular marks upon the bars.

	I.		II.	III.	IV.
	a	b			
Carbon	4·809	0·087	0·054	0·087	0·386
Silicon	0·176	0·115	0·028	0·056	0·252
Sulphur	trace	0·220	0·055	0·632	0·757
Phosphorus	0·122	0·034	traces	0·005	traces
Manganese	1·987	..	traces	..	traces
Arsenic	..	trace	..	trace	..
Iron	92·906	99·544	99·863	99·220	98·605
	100·000	100·000	100·000	100·000	100·000

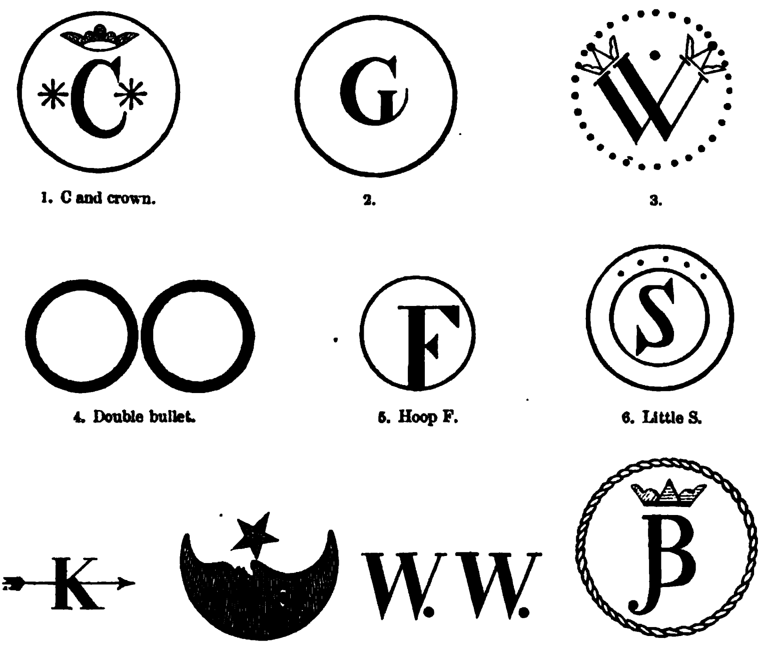
I. *a*. This is an analysis of Dannemora pig-iron, from which the (L) bar-iron is made. I received it from my friend Mr. S. H. Blackwell, and have previously inserted it under the head of Pig-iron. I. *b*. This is an analysis of (L) bar-iron, from Dannemora magnetic oxides, at the Löfsta Iron-works, Upland. It was made by my friend the late Mr. T. H. Henry, for Mr. E. F. Sanderson of Sheffield, by whom it has been generously communicated to me for publication. I have the greatest pleasure in acknowledging my obligation to Mr. Sanderson for the valuable information which I have at all times freely received from him, in connection with the subject of steel. He has placed at my disposal for publication all the analyses which have been made for him by Mr. Henry, and which have necessarily cost a large sum of money. Mr. Henry was certainly one of the most careful, accurate, and trustworthy analysts whom I have ever known. Yet I fear that, with respect to the determination of sulphur, he has been led into the same errors into which I myself have fallen, and from which I am happy to acknowledge I have been delivered by my friend Dr. David Price. Mr. Henry adopted the fusion process with nitre in a gold crucible, using a coal-gas flame. Now, this gas contains bisulphide of carbon, which, in contact with fused nitre, especially if manganese be present, becomes oxidized with, of course, the formation of sulphate of potash. Dr. Price and Mr. C. Tookey have satisfactorily investigated this point in my laboratory, and have ascertained the precise conditions under which the error may occur. It is not conceivable that Dannemora pig-iron should have contained only traces of sulphur, whilst the bar-iron made from it should have contained such a comparatively large amount as 0·22 %. These remarks con-

cerning Mr. Henry's determination of sulphur will apply equally to most of his determinations of that element. In regard to the other elements, I have reason to believe that Mr. Henry's results are thoroughly reliable.—II. By Mr. Henry for Mr. Sanderson. Sykes's double bullet, OO. This iron is made exclusively from Dannemora ores, at the Österby Iron-works, Upsala, Upland.—III. By Mr. Henry. J B mark (see below.)—IV. By Mr. Henry. K and dart (see below).

Professor Eggertz, of Fahlun, has found 0·03 % of copper in Dannemora iron.[5] It has been suggested that the superiority of the Dannemora iron is to be attributed to its relative freedom from phosphorus and copper; but Eggertz's results, abovementioned, indicate that copper is present in sensible quantity in this iron. Tunner somewhat naïvely alludes to the opinion of a celebrated French metallurgist, who assigns as the reason the "steel-like nature" of the Dannemora ores. This may be a convenient explanation, though it is certainly not a philosophical one. Tunner has not named the metallurgist, nor will I do so; yet it is plain to whom he refers.[6]

By way of illustration engravings of several of the Swedish marks are introduced. They are fac-similes from the impressions in the official Swedish book of marks.[7]

No. 1. Dannemora ores. Elfkarleö Iron-works, Upland.



1. C and crown. 2. 3.

4. Double bullet. 5. Hoop F. 6. Little S.

7. K and dart. 8. Moon and star. 9. J B.

Fig. 206.

[5] Jahres-Bericht, Wagner, 1862, p. 9. [6] Eisenhuttenwesen in Schweden, p. 13.
[7] Stämpel-Bok. Stockholm, 1845.

No. 2. Dannemora ores. Gimo Iron-works, Upland.
No. 3. Dannemora ores. Strömberg Iron-works, Upland.
No. 4. Dannemora ores. Österby Iron-works, Upland.
No. 5. Dannemora ores. Forssmark Iron-works, Upland.
No. 6. Dannemora ores. Skebo Iron-works, Upland.

No. 7. Magnetic oxides from Bispberg and Relingsberg, and red oxide from Noberg. Kloster Iron-works, Dalecarlia. The Kloster Iron Company has several works, and the iron from each has a distinctive mark or "brand;" but the mark figured is on all the varieties.

No. 8. Persberg magnetic oxides. Borgvik Iron-works, Wermland. The matrix is amphibole. No flux is required. The ores contain traces of phosphorus and comparatively small proportions of manganese.

No. 9. Dannemora ores. Gysinge Iron-works. Province of Gestrikland, adjoining Dalecarlia.

Russian Iron.

No better iron in the world is made than in Russia. Charcoal is exclusively used as fuel.

	I.	II.
Carbon	0·272	0·340
Silicon	0·062	trace
Sulphur	0·234	0·066
Phosphorus	..	..
Arsenic	traces	..
Manganese	0·020	trace
Iron	99·412	99·594
	100·000	100·000

I. Analysis by Mr. Henry for Mr. Sanderson. The bar-iron was the well-known CCND.—II. By Mr. Henry. Mark, K.3KБ.

Boat-plates.

This is the commercial term for rolled plates which are used in the construction of iron ships. Owing to competition and the cutting down of prices, boat-plates have acquired an unenviable notoriety for badness. The rubbish, scarcely deserving the name of iron, which has been, and there is too much reason to believe still is, used in their manufacture, is well known to every person engaged in the iron trade. Where security to life, to say nothing of valuable cargoes, is of prime importance, it is scandalous that such plates should be tolerated. There are, I admit, good boat-plates as well as bad ones, but the latter greatly predominate. In the Swedish department of the International Exhibition, 1862, there was a striking illustration of what really good boat-plates should be, and of the resistance they are capable of affording in cases of danger at sea. I refer to the fore part of an iron paddle steamer, 200 ft. long, and of 120 horse power, which, during a fog in September, 1860, and while going at the rate of 8 or 9 knots an hour, struck on a rock. The part struck was crumpled up like paper; and yet the vessel got off and proceeded without difficulty to Stockholm, about 100 miles distant. The plates were made at the Motala Iron-works. There was nothing more interesting or more important

to us, as a great maritime nation, than the specimen in question. It attracted great attention, and has been presented to the South Kensington Museum, where, notwithstanding its ugliness, it is to be hoped it will be carefully preserved and exhibited in a conspicuous place. The authorities of that Institution may be assured that in the whole collection there is not an illustration of more substantial practical value.

ARMOUR-PLATES.

This term is now generally applied to massive wrought-iron plates, with which ships of war are coated externally, where they are accessible to shot or shells; and since the adoption of this means of defence, great and rapid progress has been made in the manufacture of these plates. Experiments have been conducted by the Governments of this country, of France, of Prussia, of Austria, and of Italy, with a view to ascertain the best quality of iron for the purpose, and the best mode of manufacture. Information of the highest value has thus been acquired, yet the subject is far from being exhausted at present.

With regard to quality, it seems to have been decided that the iron should be as tough and soft as possible; and that steel, properly so designated, should especially be avoided. It might have been supposed that certain kinds of steel which possess far greater tensile strength than any kinds of wrought-iron would have been most suitable; but experiments have established the contrary. In determining tensile strength, the force employed to effect rupture is *slowly* applied; and results are obtained in this manner which may cease to be applicable in cases where impact takes place at such high velocities as 1200 ft. and 1600 ft. per second. In an early part of the present volume the subject of fracture under this latter condition was considered.

It is a question whether hammering, or rolling, or a combination of both will yield the best result; and each of these three methods of manufacture has its advocates; though perhaps the majority of persons have declared in favour of rolling. The fact is, that equally good plates have been produced by each method, when the manipulations have been conducted with proper skill. No large armour-plates are now made less than 4½ in. in thickness; as thinner plates would be immediately destroyed by the powerful artillery of recent times, and the resistance of superimposed plates, however firmly fastened together, is greatly inferior to solid plates of the same aggregate thickness.

Rolled armour-plates.—The credit of having produced the first large armour-plates by rolling is due to Messrs. Beale and Co., of the Park Gate Iron-works, Yorkshire; but plates of this kind are now rolled by several firms, of which that of John Brown and Co., of Sheffield, deserves special mention. This firm has entered upon this difficult branch of manufacture with a spirit of enterprise and a persevering energy which do honour to the British nation. They have erected for the purpose at Sheffield a gigantic mill, which was opened with much ceremony, April 9th, 1863, the Lords of the Admiralty, engineers, and others interested in the subject being present. But previously this

firm had produced armour-plates which from their magnitude and finish had excited the astonishment of all persons acquainted with the difficulties necessarily involved in the manipulation of such large masses of iron under the rolls. Messrs. Brown and Co. sent to the International Exhibition, 1862, two plates of the following dimensions and weights: No. 1. Length 21 ft. 8 in., width 4 ft. 2 in., thickness 6¼ in., weight 10 tons 12 cwts.—No. 2. Length 24 ft., width 3 ft. 8 in., thickness 5 in., weight 7 tons 17 cwts. These were admirable specimens of workmanship, so far as any judgment could be formed from an inspection of their surfaces and edges. With the exception of being planed at the edges, they appeared as when they left the rolls. They were made of "best new scrap" iron, obtained, it is stated, from a mixture of Swedish, Derbyshire, and Shropshire refined pig-iron. It was balled under a 4-ton steam-hammer, piled under a 6-ton helve, rolled into bar, re-rolled into slabs, all crossed, then re-rolled into what are termed "moulds," and lastly, rolled into finished plates. The selling price of these plates (1862) was from 35*l.* to 45*l.* per ton. On the opening of the new mill, a plate 12 in. in thickness was rolled. It will be remarked that I express myself with a certain degree of reserve as to quality, not with the least intention of disparagement, but because experience has taught me that the excellence of an armour-plate can only be determined by actual trial with heavy shot. The Mill Wall Company have recently produced rolled plates which have not been surpassed by any manufactured elsewhere.

The difficulty of manufacture, for reasons previously assigned, greatly increases in proportion to the *thickness* of the plate. Tendency to lamination in rolled plates under the impact of shot is the great evil, which has not yet been effectually surmounted, if indeed in the very nature of things it be possible to do so. Plates which from an examination of their exterior have appeared perfect, have been broken and laminated to an extent which would hardly be credited by persons who have not witnessed the fact. This is due to imperfect welding of the contiguous surfaces of the layers of iron composing the plates, caused by interposed cinder, which, however liquid it may have been in the reheating furnace, it is not possible should ever be completely expelled, even if the surfaces of the superimposed component layers were perfectly flat and smooth like plate glass; much less is it possible, since those surfaces are always more or less uneven. It is extremely interesting and instructive to observe how the cinder is diffused, lying in small depressions or sometimes extending over a comparatively large area. Never has the inner structure of thick masses of iron been so completely disclosed as by the impact of shot; and I do not see how it would be possible in any other way to obtain the same amount of knowledge concerning it.

Hammered armour-plates.—Large armour-plates have been manufactured under the hammer, which, on trial by shot, have proved equal to any made by rolling. The Thames Iron Company have produced excellent hammered plates. It is maintained by some persons that a hammered plate is more likely to be uniform in quality than a rolled

plate. Each method of manufacture has advantages and defects peculiar to itself. Hammered plates are supplied at the same prices as rolled plates. In the International Exhibition, 1862, a large hammered armour-plate of the following dimensions was exhibited by the Mersey Steel and Iron Company:—21 ft. 3 in. long, 6 ft. 3 in. wide, 5½ in. thick. Its superficial area was 133 ft. square, and it weighed upwards of 13 tons. It was forged under the steam-hammer, and neither "smithed nor tooled" afterwards. It was a remarkable piece of forging in every respect. The plate would have been made from 15 ft. to 20 ft. longer "if space could have been obtained." There was ample space, as it turned out; and it is much to be regretted that any restriction as to space for such an object should have been imposed by the Commissioners. Had it been showy, though comparatively worthless, room would doubtless have been found for it.

Messrs. Petin, Gaudet, and Co., in France, have produced excellent armour-plates of about 4 in. in thickness, though in external appearance they have been inferior to similar plates of British manufacture; thus showing that a comparatively rough exterior furnishes no criterion of quality, while a smooth and well-finished surface may considerably increase the price without any corresponding advantage.

The desideratum in all armour-plates is that they shall bulge with the least possible amount of cracking. Large radiating fractures at the back indicate brittleness, and should immediately condemn a plate.

During the last three years extraordinary advance has been made in England in the quality of armour-plates; and, probably, before long they will be everywhere manufactured by rolling.

For the sake of comparison I subjoin analyses of the iron of several kinds of armour-plates:

Per cent.

	I.	II.	III.	IV.	V.	VI.
Carbon	0·143	0·033	0·230	0·044	0·170	0·016
Silicon	..	0·160	0 014	0·174	0·110	0·122
Sulphur	0·058	0·121	0·190	0·118	0·058	0·104
Phosphorus	0·030	0·173	0·020	0·228	0·089	0·106
Manganese	..	0·029	0·110	0·250	0·330	0·280
Cobalt	..	traces	traces	traces	traces	traces
Nickel	..	..	..	..	..	traces

I. Iron used for the plates of the French frigate 'La Gloire:' it hardened sensibly when plunged red-hot into mercury. II. Iron of a plate made by the Thames Iron Company. III. Iron of a plate made by Messrs. Shortridge and Howell. Although containing only a very small quantity of phosphorus, yet the plate was bad, as an armour-plate, from approximating too much to steel in quality, in consequence of the comparatively large proportion of carbon. IV. Iron of a plate made by Messrs. Beale and Co. V. Iron of a plate made by the Weardale Company. It was also too steely. VI. Iron of a plate made by the Lowmoor Company. This analysis has been previously inserted.

Nos.	Specific gravity.	Tensile strength in tons per square inch.	Relative resistance to punching.
II.	7·7035	23·354	907
III.	7·9042	27·032	1168
IV.	7·6322	24·171	873
VI.	7·8083	24·644	1000

The specific gravity, tensile strength, and resistance to punching were determined by Mr. Fairbairn. I now subjoin the electric conductivity of the iron of several of the plates, computed by Mr. Matthiessen from his own observations.

	Conductivity at 0°C.	Percentage decrement in conductivity between 0°C. and 100°C.	Deduced conductivity at 0°C.
Electrotype iron ...	100	38·3	..
No. II.	91·8	36·0	102·7
No. III.	91·8	36·1	102·1
No. IV.	72·8	34·1	..
No. VI.	84 6	34·7	99·2

Mr. Matthiessen states that he found it difficult to draw No. IV. into wire.

MISCELLANEOUS OBSERVATIONS.

Treatment of Slags rich in Iron.

Formerly the tap-cinder from the puddling-furnace was thrown away or used in mending roads, notwithstanding the large amount of iron which it contains.[8] I have seen it thus wasted 20 years ago in South Staffordshire; and my friend, Mr. John Dawes, appears to have been amongst the first to recognise its value as an iron-producing material; for at about the period above-mentioned I saw an accumulation of many thousands of tons of it near the Bromford blast-furnaces, which he then worked in partnership with his brothers. Mr. Dawes expressed to me his conviction that the period was then at hand when it would be utilized, and his prediction did not long await fulfilment. We hear a great deal about the badness of "cinder iron," as it is called, from engineers and others; and I have reason to know that in some instances at least the impression prevailed that the iron derived from it was actually impregnated with an inordinate amount of cinder. The objection to the use of tap-cinder is due to the fact that it contains phosphoric acid in larger proportion relatively to the iron present than most of the ores smelted in this country; and that, consequently, it will tend to produce a cold-short and tender quality of iron. But, in the case of pig-iron designed for fine castings, in which great strength is not necessary, and a very liquid metal is required, the presence of phosphorus may be advantageous rather than otherwise. Moreover there are some kinds of iron-ore raised and smelted in Great Britain which, in relation to the amount of iron in them, are quite as rich—and sometimes even richer—in phosphoric acid than tap-cinder. When, therefore, engineers specify in their contracts for rails, etc., that "mine iron" shall be used to the exclusion of cinder, they may readily be defeated in their object, unless they specify at the same time that particular kinds of ore or "mine" shall not be employed.

[8] Dr. Priestley states that his brother-in-law, Mr. Wilkinson, used with advantage a certain proportion of "finery-cinder" in the smelting of iron. He regarded it "as iron increased about one-third in weight by imbibing water, though with the loss of its own phlogiston." Experiments and Observations on different kinds of Air, 3. p. 504, 1790.

In smelting tap-cinder, which is usually done in conjunction with iron-ores, Mr. S. H. Blackwell informs me that it is desirable to subject it to a preliminary roasting; or, in other words, to convert it into "bull-dog," as a saving of coke, to the extent even of 30 %, may be thereby effected. During this process of roasting, we have seen that the protoxide of iron is more or less completely changed into sesquioxide, and that the cinder is rendered comparatively light and spongy, becoming, *pro tanto*, more accessible to the reducing action of the carbonic oxide of the blast-furnace. The reduction of the oxide of iron to the metallic state will also partially take place at a temperature below that at which silicate of protoxide could be again formed, the silica in "bull-dog" existing, doubtless, in an uncombined state. Besides, there is another advantage resulting from roasting, namely, the liquation of cinder richer in phosphoric acid than that which is left to form the "bull-dog."

Various expedients have been proposed of incorporating the cinder, previously to smelting, with substances which may combine with the phosphorus and sulphur present, and prevent these substances from passing, either wholly or partially, into the pig-iron.

Lang mixes tap and flue-cinder, reduced to the size of millet-seeds, with carbonaceous matter and milk of lime to the consistency of thick paste, or common mortar. The mass is left to dry in heaps, when it becomes solid and hard.[1] It is then broken in pieces, and so smelted. The following analyses of pig-iron produced at Missling from cinders thus prepared are cited in proof of the efficacy of the process:—

	I.	II.	III.	IV.
Iron	94·03	95·32	96·88	94·50
Carbon	5·14	3·50	2·40	2·50
Silicon	0·40	0·62	0·50	2·46
Sulphur	traces	traces	traces	0·06
Phosphorus ...	0·32	0·27	0·22	0·11
Manganese ...	..	..	traces	traces
	99·89	99·71	100·00	99·63

I. Spiegeleisen. II. Crystalline white pig-iron. III. White pig-iron. IV. Grey pig-iron.

A similar process was patented by Mushet in 1822.[2] The slags or cinders were reduced to "a small size by shotting" or otherwise, and then mixed with $\frac{1}{4}$ or $\frac{1}{6}$ of slaked lime. The mixture was moistened, and so charged into the blast-furnace.

Professor Fleury read a paper to the Franklin Institute, Philadelphia, August 20, 1863,[3] in which he stated that he had succeeded in making good cast and wrought-iron, as also good cast-steel, from tap and mill-furnace cinders! The finely-ground cinder is mixed with a proper per centage of powdered burnt lime (*i. e.* unslacked), and

[1] Jahres-Bericht, Wagner, 1861, p. 34.
[2] A. D. 1822, Aug. 20. No. 4697. Abridgments, p. 26.
[3] Journ. of the Franklin Institute, 3rd ser., 46. Sep. 1863. p. 214.

after wetting the mixture with water it is exposed to the drying influence of the atmosphere. The dry compound, treated in a common puddling-furnace like pig-iron, yielded 50 % of wrought-iron, which, however, was somewhat red-short, owing to the retention of traces of sulphur. We are informed that the last traces of sulphur were extracted by slaking the lime with water containing a small per centage of a chlorine salt. The process, it is asserted, is also applicable to the working of siliceous ores, and can be performed in the puddling, cupola, or blast furnace. "The preparation of the cinder, cost of lime, salt, etc., does not exceed two dollars per ton; and if properly worked, the result is invariably a good quality of iron." Patents for this improvement, we are told, have been obtained both in the United States and Europe. The beneficial result is attributed to the decomposition of the silicate of iron by the lime during the process of hydration, whereby silicate of lime is produced. Now, we have seen that in the case of siliceous ores, reduction of the silicon in a sensible degree is prevented by the presence of lime, provided the latter is intimately mixed with the ore. But how to effect such admixture economically is the difficulty. That lime should extract phosphorus from cinder is not very intelligible, seeing that the phosphorus of phosphate of lime is reduced by the joint action of carbon and iron. Besides, even if Fleury's process should succeed, it is doubtful whether a patent for it in this country could be sustained.

Mending broken Rolls.

An account of the process of mending rolls has recently been published in the 'Annales des Mines' by a French mining engineer, who saw it in operation at the iron-work of Tamaris, near Alais.[4] This process consists in strongly heating the broken end in a coke fire, and then pouring on it in a suitable mould, previously adjusted for the purpose, very hot molten pig-iron, allowing the metal to continue running through the mould until the surface to be soldered begins to liquefy. When this occurs, the hole by which the metal escapes from the mould is stopped, and the latter becomes filled with metal.

Meugy witnessed the reparation of a roll, of which a neck and one groove had been broken off in rolling. The roll was fixed vertically, with the broken end uppermost; and around this was a coke fire in a square grate containing about 100 kil. (about 2 cwts.) of coke. This preparatory heating lasted 1½ hour. At a given moment the grate was removed, the fuel quickly thrown upon the ground, and extinguished with water. The top of the roll being now red-hot, haste was made to surround it with a frame, which was rapidly and completely filled up with casting sand. After having levelled the sand and blown off the dirt from the end to be soldered with a pair of bellows, a mould previously ready, and having within a cavity of the form of a sort of

[4] Sur un Procédé usité en France pour le Soudage de la Fonte. Par M. Meugy. Ann. des Mines, 5 s. 18. p. 59, 1860.

double truncated cone, of which the base was a little larger in diameter than that of the piece to be added, was placed on the top. In this mould was a tap or exit-hole, corresponding to an external groove leading to channels destined to receive the excess of pig-iron. By means of a crane, a large pot, containing about 500 kil. or 600 kil. of molten pig-iron, was raised a little above the mould, and the metal poured in. Scintillation occurred round the mould, and the pig-iron filled the external channels, where it solidified in the form of pigs. The head workman, who directed the operation, and who sounded every moment the surface of the piece to be soldered with an iron rod, ascertained when the surface of the roll began to melt; and when he thus found that the old pig-iron had liquefied to the thickness of about $0^{m}03$ (1·18 in.), which happened in 4 or 5 minutes, after pouring from 300 kil. to 400 kil. of pig-iron, he judged that it was time to stop the running of the metal from the mould. The tap-hole was then stopped, and pig-iron allowed to flow in until the mould became filled. This done, a second mould, containing within a cylindrical cavity representing the neck of the roll, was placed, by means of a crane, on the other mould, the frames of both exactly fitting together in the usual manner. The joints being luted with a little clay, metal was poured afresh into the uppermost mould. At last a third mould, also cylindrical, was adjusted, and pig-iron poured in, which formed a dead-head to be subsequently removed. This head, by its pressure, consolidated the soldered joint by binding more intimately the new with the old pig-iron. It then only remained to allow the whole to cool, and, when cold, to turn the soldered part in a lathe.

The process should be rapidly performed, and ought not to last longer than ½ hour, exclusive of the time needed for the preparatory heating in the coke fire. According to Meugy, a finished roll weighing 1100 kil. cost 616 francs; but, as old pig-iron, was only worth 132 francs. The cost of reparation by this process amounted to 115·8 francs, so that there was a clear gain of 368 francs.

In this country broken rolls are mended in some establishments; but I believe the practice is not general. The process of reparation resembles, but is more simple than, that above described. The roll is set vertically, with its broken end uppermost. A sand mould within an iron frame is fixed on the top, and molten pig-iron is poured in, and kept flowing out at a hole on one side near the bottom of the mould, until the broken end is in a state of incipient fusion, when the hole at the side is stopped, the mould filled with metal, and the whole left to cool. There is no dead-head. At the Mill Wall Company's Iron-works I saw a roll thus mended satisfactorily, of which the neck was 11 in. and the roll 22 in. in diameter (Sep. 1863). I am assured that the process is satisfactory in all respects.

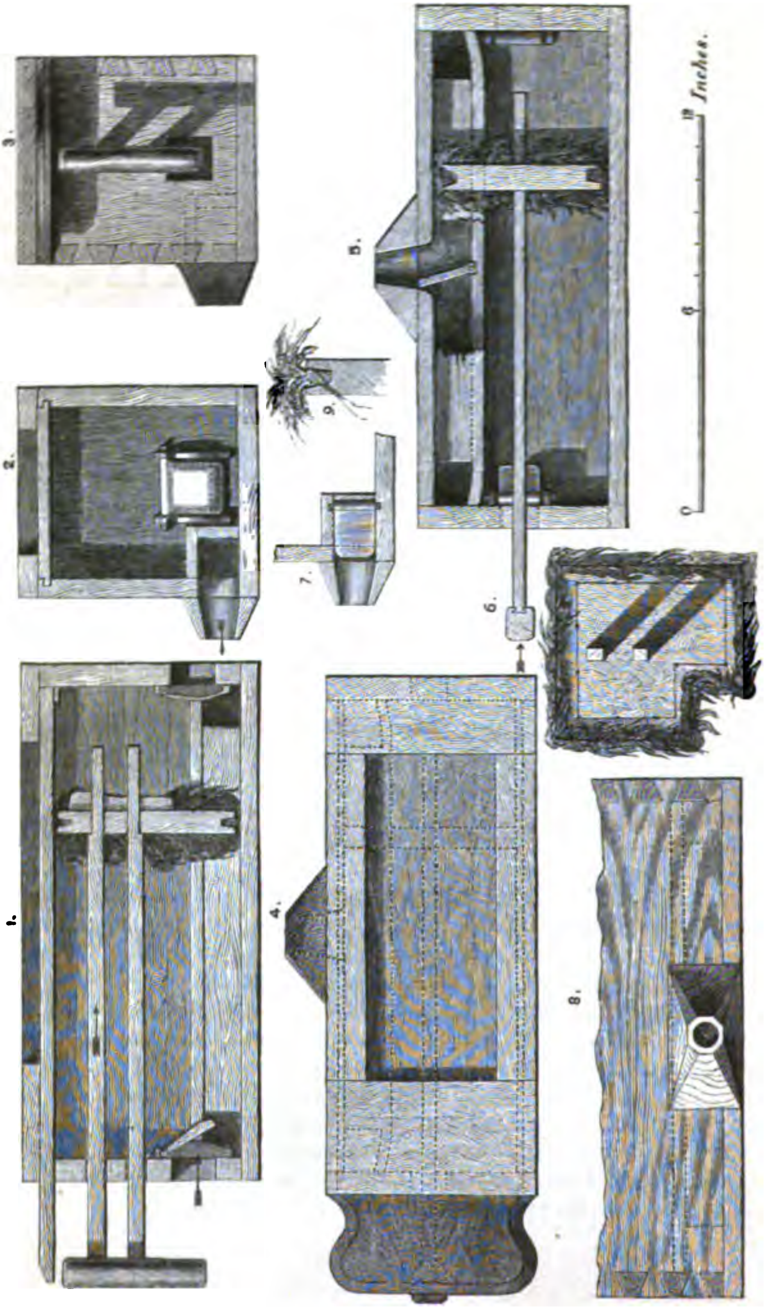


Fig. 267. Chinese Blowing Machine.

Chinese Method of mending cracked Cast-iron Utensils.

The Chinese use extensively for culinary purposes, such as boiling rice, etc., circular bowl-like vessels or pans of thin cast-iron. These pans were long ago described and figured by Count Rumford; and he alludes to the ingenious method of mending them by itinerant tinkers.[5] At my request, my friend Dr. Lockhart, the indefatigable and well-known Chinese medical missionary, now directing an hospital at Pekin, procured a specimen of one of the mended pans, and the apparatus employed in the process, which he presented to the Museum in Jermyn Street, where they may now be seen. The pans are difficult to make, on account of their thinness, and yet they are commonly manufactured by the Chinese themselves. I have received the following description from Dr. Lockhart:—

"These boilers are much used for cooking rice and other vegetables, and are made very thin, their chief excellence in the eyes of the Chinese being their thinness, as, owing to this quality, very little firewood is required to boil water in them. Some years ago a large quantity of boilers were made in Birmingham of the same shape as the Chinese vessels; but the natives would not buy them, as they were too thick, and wasted firewood. The boilers being so thin, are very apt to break and crack, in which case they are handed to an artisan, who, with the articles of his trade slung in baskets across his shoulders, goes about the streets, crying out 'Boilers to mend; Jars and other vessels repaired!' One of these men is frequently seen repairing a boiler, which is not only cracked, but has a piece broken out of it, say an inch square. He first cleans the edge of the fracture by scraping it with a chisel, and rubbing it with a piece of brick; after which he inverts the vessel and places it on a low tripod stand, so that he can easily use his hands inside and outside of it. By his side are his box of tools and various other articles of his trade. He takes a little crucible, of the size of a thimble, and places in it a small scrap of cast-iron; the crucible is then put into a small furnace about as large as the lower half of a common tumbler (that in the Museum is somewhat larger); this is filled with charcoal, and, by means of bellows, great heat is produced, and the iron is shortly melted. The workman now drops the melted iron on a piece of felt, covered with some charcoal ashes or dust, which he holds in his left hand, introduces it into the inside of the inverted vessel, and presses it against the part to be repaired, at the same instant striking the melted metal that protrudes through the hole or crack with a small roll of felt, covered also with ashes. This process he repeats till the deficiency in the boiler is filled up. He then breaks off any rough projecting parts of the new surface, rubs it over with a piece of broken tile or brick, so as to make it tolerably smooth; and having tried whether his work is perfect, by putting

[5] Essays, Political, Economical, and Philosophical. By Benjamin Count of Rumford. 1802, 3. p. 298.

water into the vessel, hands it to the owner, and charges 3*d*. or 4*d*. for the job."

A detailed account of the process by Mr. Balestier, U. S. Consul at Singapore, was published in the United States in 1850.[6] It was described in 1794-5 by Van Braam, the second in command of the Dutch embassy to Pekin, who afterwards settled in the United States. In this description the globule of molten cast-iron is stated to be poured upon a piece of *wet* paper; in which case the Chinese availed themselves of the spheroidal state of water. Mr. Balestier's account agrees substantially with that of Dr. Lockhart. There is no actual soldering; but the cracks are united by little rivet-like pieces of cast-iron, produced, of course, without hammering.

The blowing apparatus is extremely ingenious and effective, and is wholly of wood, except the packing and wire hinges of the valves. It is represented in the accompanying engravings, which have been executed from accurate drawings of the bellows in the Museum in Jermyn Street. It consists essentially of a rectangular wooden box, with a piston working horizontally. The engravings will render the construction perfectly intelligible. Fig. 207, 1. Longitudinal vertical section. 2. Cross section through the middle, showing a hanging valve, opening inwards, and the nozzle. There is a similar valve at the opposite end. 3. Elevation of the end, through which the handle of the piston protrudes. 4. Plan of the top, which is made to slide out, in order to effect any necessary repairs, etc., within. 5. Horizontal longitudinal section, showing the valve at the nozzle, and which, moving alternately by the pressure of the air, from one side to the other, shuts off the nozzle from the space on each side the piston respectively. There is a wooden passage for the air at the bottom on the nozzle side, which is shown partly cut away. 6. The piston, which is packed with feathers. This packing seems to answer admirably. We have seen that it is used in India, Borneo, and elsewhere. 7. Valve at the nozzle. 8. Side elevation, partly cut away on account of deficient space in the engraving. 9. Cross section of the edge of the piston, showing the mode of fastening on the feathers with string. The apparatus is, it will be perceived, double acting. It gives an excellent and pretty uniform blast, and may be worked with ease.

The furnace is a little shallow circular open vessel of sheet-iron, 5½ in. in diameter at the top, and 5½ in. high, lined with fire-clay, and having a few little bars for the grate, *below* which the blast is introduced, exactly in the same manner as in the furnace known as Faraday's.

In the American report cited it is remarked, "Perhaps no device can be named more characteristic of Oriental ingenuity of the most mechanical people of the East than this. It is one that could only have occurred where ages of experience in the treatment of the metals

[6] Report of the Commissioners of Patents for the year 1850; Part I. Washington, 1851. p. 406. It is illustrated with an interesting sketch of a tinker at work.

had elapsed. The idea of an ordinary artisan fusing iron with a handful of charcoal, and handling the glowing liquid as if it were but melted wax or tallow, would be considered by our founders as belonging rather to romance than to reality. Every year thousands of vessels, large and small, are with us thrown aside—costly sugar pans of planters, and the more capacious vessels of soap-boilers and brewers, as well as culinary caldrons, that might be restored to soundness by this simple method, and at the most trifling charge." There is, I fear, reason to doubt whether thick vessels of cast-iron could be mended so cheaply and efficaciously as the American writer seems to suppose.

PRICES OF BRITISH MERCHANT-IRON.

I have pleasure in presenting the following elaborate tabular statement of the prices of every description of British merchant-iron in 1863, which has been obligingly prepared, at my request, for this work by Messrs. William Bird & Co., of 2, Laurence Pountney Hill.

LIST OF PRICES OF BRITISH MERCHANT-IRON.

Ordinary Sizes.	Staffordshire Iron, delivered in Liverpool. Ordinary Crown Quality.		Superior Crown Quality.		Charcoal.		Puddled Steel.		Newcastle and Middlesbrough Iron, f. o. b. (free on board) in the Tyne or Tees, or West Hartlepool. Ordinary Quality.		Superior Crown Quality.	
	Per ton (of 2240 lbs.).								Per ton.			
	£. s.	£. s.	£. s.	£. s.	£. s.	£. s.	£. s.	£. s.	£. s.	£. s.	£. s.	£. s.
Bar iron, rounds, squares, and flats	8 5 to	8 10	9 0 to	9 10	17 0 to	17 10	10 10 to	17 0	7 5 to	7 10	8 0 to	8 15
Do. for cable bolts	10 10		11 0	11 10	..		..		8 10	9 0	8 15	9 15
Do. for horse-shoes	9 0	9 5	9 10	10 0	..		..		8 0	8 10	8 15	9 5
Do. imitation Swedish	9 5	9 10	10 0	10 10	..		..				..	
Sash iron, single and double, all patterns	11 10	12 0	12 5	13 10	..		..		..		10 10	12 15
Half round, oval, octagon, convex, waggon, and bevelled iron	9 0	9 10	9 15	10 10	..		..		..		9 5	10 0
Fire bars, according to section	8 10		9 0	9 10	..		..		7 10	8 0	8 5	8 15
Rails for collieries, 12 to 18 lbs. per yard	8 10		9 5	9 15	..		17 0	20 0	7 15	8 5	8 10	9 10
Do. for permanent way	8 5	8 10	9 0	9 10	.		12 0	20 0	7 10	8 0	8 0	8 10
Do. for switches and crossings	8 10	8 15	9 10	9 15	..		15 0	20 0	8 5	8 10	8 15	9 15
Tram plates for collieries, etc.	8 10	9 0	9 0	10 0	..		..		7 15	8 5	8 10	9 10
Fish plates for rails	8 10	9 0	9 5	10 0	..		10 10	17 0	7 15	8 5	8 15	9 15
Railway tyre bars for locomotive wheels	11 0	12 0	12 5	13 10	..		25 0	30 0	11 0	12 0	11 10	13 0
Do. do. for carriage and waggon wheels	11 0	12 0	12 5	13 10	..		24 0	20 0	9 10	10 15	10 10	11 10
Spoke and ring iron for railway wheels	8 0	9 0	9 0	10 0	..		..		..		8 0	9 0
Scroll and figured iron	..		11 5	12 0	..		..		..		..	
Tip iron, grooved, ½, 7/16, and ⅜ inch	10 5	10 10	10 10	11 0	..		..		..		..	
Do. solid	10 0	10 5	10 0	10 10	..		..		..		..	

Wire rods, No. 0 to 4, for fencing	10 5		10 10	10 15		..	18 10	18 15		..		..
Do. do. for wiredrawing	10 5	10 15	11 0	11 10		..		..		..		..
Nail do. No. 00 to 20 rod gauge	8 5	8 10	9 5	9 10	17 10	18 0		..		..	8 15	9 5
Rivet iron	10 5	10 10	10 10	11 0		..	21 0			..	10 15	13 0
Nut and crank do.	10 5	10 10	10 10	11 0		..	21 0			..	10 15	13 0
Bullet do. for fluted cotton rollers	11 0	13 10	13 10	17 0		..		..		..		..
Swarf do. do.		..	19 10	25 0		..		..		..		..
Angle iron	9 5	9 10	9 15	10 0		..	19 0	24 0	8 10	9 0	9 5	10 0
Do. bulb	10 5	10 10	10 10	11 0		..	20 0	24 0	9 5	9 15	9 10	10 10
Do. double	12 15	13 0	13 5	13 10		..		..		..		..
Do. roofing or channel	10 15	11 0	11 10	12 0		..		..		..	11 10	11 15
Tee iron	9 15	10 0	10 5	10 10		..	21 0	26 0	9 0	10 0	9 5	10 5
Do. for deck beams	12 0	13 10	13 10	15 10		..	24 0	28 0	9 15	10 10	10 5	11 0
Girders, bulb beams, etc.	10 0	18 0	10 10	18 0		..	24 0	30 0	9 15	12 0	10 5	15 0
Taper bars for ship's knees, etc.		..	10 0	10 10		..		..		..		..
Hoop iron	9 5	9 10	9 10	10 0		..		..		..	9 10	10 0
Sheet do., singles to No. 20 W. G.	10 5	10 10	10 10	11 5	18 10	19 0		..		..	10 10	11 0
Do. do. best for galvanizing and corrugating	10 5	10 15	11 0	12 0	18 10	22 0	22 0	24 0		..		..
Nail sheets, all gauges	10 10		11 0	11 15		..		..		..		..
Canada plates, including boxes	13 10	14 0	14 0	14 5		..		..		..		..
Boiler plates	10 5	10 10	10 10	11 5	18 10	22 0	22 0	24 0	10 10		10 15	11 15
Boat do.	10 0	10 10	10 10	11 0		..	18 0	21 10	10 10		10 10	11 0
Gasometer do.	10 5	10 10	10 10	11 5		..		..	10 10	11 0	11 0	12 0
Flooring or chequered do.	12 10	12 15	12 15	13 5		..		..		..		..

Improved qualities of each make, as "Best," "Best Best," "Best Best Best," at an advancing rate of from 10*s*. to 80*s*. per ton extra.

Discount for cash 3 per cent.

Delivery can be made in any other ports than the abovenamed with the usual difference for increased or diminished cost of transport.

LIST OF PRICES—*continued.*

Ordinary Sizes.	Yorkshire Iron, delivered in Liverpool. Ordinary Quality.	Yorkshire Iron, Superior Quality.	Yorkshire Iron, Lowmoor or Bowling.	Welsh Iron, f. o. b. in Wales. Ordinary Quality.	Welsh Iron, Superior Quality.	Scotch Iron, f. o. b. in Glasgow. Ordinary Quality.	Scotch Iron, Superior Quality.
	Per ton.	Per ton.	Per ton.	Per ton.	Per ton.	Per ton.	Per ton.
	£. s. £. s.	£. s. £. s.	£. s.	£. s. £. s.	£. s. d. £. s.	£. s. £. s.	£. s. £. s.
Bar iron, rounds, squares, and flats	8 15 to 9 5	16 10 to 17 0	18 0	6 15	6 17 6 to 7 0	8 5 to 8 10	8 10 to 8 15
Do. for cable bolts	9 15 11 5	16 10 17 0	18 0	8 5 to 8 10	8 10	9 5 9 10	9 10 9 15
Do. for horse-shoes	9 15 11 5	16 10 17 0	18 0	..	8 10 9 0	..	..
Sash iron, single and double, all patterns......	..	..	21 0	..	..	10 15 11 0	11 0 11 10
Half round, oval, octagon, convex, waggon, and bevelled iron	9 5 9 15	18 0 20 0	21 0	7 0 7 5	7 0 7 10	8 5 8 10	8 10 9 0
Fire bars, according to section	8 15 9 5	16 0 17 0	18 0	6 15 7 0	7 0 7 10	8 5 8 10	8 10 9 5
Rails for collieries, 12 to 18 lbs. per yard	9 0 9 10	..	..	7 0 7 5	7 0 7 10	9 5 9 10	9 10 9 15
Do. for permanent way	8 10 9 5	..	18 0	6 15	6 15 7 0	8 0 8 10	8 10 8 15
Do. for switches and crossings	8 10 9 10	..	18 0	7 0 7 5	7 0 7 10	..	..
Tram plates for collieries, etc.	9 5 9 15	..	..	7 0 7 5	7 0 7 10	9 5 9 10	9 10 9 15
Fish plates for rails..................................	8 15 9 15	..	..	7 10 7 15	7 10 8 10	8 10 8 15	8 10 9 0
Railway tyre bars for locomotive wheels	11 0 14 0	20 0 21 0	21 0	..	21 0 23 0	10 10 11 0	11 0 13 0
Do. do. for carriage and waggon wheels	11 0 13 0	20 0 21 0	21 0	..	21 0	10 0 11 0	10 10 12 0
Spoke and ring iron for railway wheels	8 15 9 15	..	..	..	..	..	..
Scroll and figured iron	..	..	..	..	..	..	..
Tip iron, grooved, ½, 7/16, and ⅜ inch	..	..	..	..	..	11 0 11 5	11 0 12 0
Do. solid	..	..	..	..	..	11 0 11 5	11 0 12 0

Nail rods. No. 00 to 20 rod gauge............	..	..	23 0	7 5	7 0 7 10	8 5 8 10	8 10 8 15
Rivet iron..	10 10 12 0	16 10 17 0	18 0	..	..	10 0 10 5	10 0 11 0
Nut and crank do.	10 10 12 0	16 10 17 0	18 0	..	..	10 0 10 5	10 0 11 0
Angle iron	9 10 10 0	20 10 21 0	22 0	..	8 10 9 0	9 5 9 10	9 10 9 15
Do. bulb	10 10 11 0	..	..	..	8 15 9 10	10 5 10 10	10 10 10 15
Do. roofing or channel	..	..	..	..	10 0 11 0	..	..
Tee iron	10 0 10 10	20 10 21 0	22 0	..	9 0 9 10	10 5 10 10	10 10 10 15
Do. for deck beams........................	12 0 15 0	..	..	..	9 10 12 0	10 5 11 0	10 10 12 0
Girders, bulb beams, etc. ...	11 0 18 0	..	..	..	9 10 15 0	9 10 12 0	9 15 13 0
Taper bars for ship's knees, etc...................	..	..	..	..	..	..	..
Hoop iron...	9 15 10 5	..	20 0	..	..	9 15 10 0	10 0 10 5
Sheet do., singles to No. 20 W. G.	10 15 11 5	..	..	..	10 10 11 10	10 0 10 5	10 0 10 10
Do. do. best for galvanizing and corrugating	11 15 13 0	..	..	..	11 10 12 0	10 5 10 15	10 15 11 10
Nail sheets, all gauges............................	..	..	..	..	..	10 0 10 5	10 0 10 10
Canada plates, including boxes	..	..	..	..	14 0 15 0	..	..
Boiler plates..	10 15 11 5	20 10 21 0	22 0	9 15 10 0	10 0 10 10	10 10 10 15	10 10 11 0
Boat do.	10 10 11 0	..	..	9 15 10 0	10 0 10 10	10 0 10 5	10 0 10 10

Improved qualities of each make, as "Best," "Best Best," "Best Best Best," at an advancing rate of from 10s. to 80s. per ton extra.

Discount for cash 3 per cent.

Delivery can be made in any other ports than the abovenamed with the usual difference for increased or diminished cost of transport.

LIST OF EXTRAS PER TON OF 2240 lbs.

STAFFORDSHIRE IRON.

The ordinary sizes of bar iron are from ½ to 3 inches round and square, and from 1 to 6 inches wide by ¼ to 1 inch thick.

Rounds and Squares.

15/32	7/16	13/32	3/8	11/32	5/16	9/32	1/4	7/32	3/16	inches.
5/	10/	15/	20/	25/	30/	35/	40/	60/	80/	per ton extra.

3¼ to 3½	3¾ to 4	4¼ to 4½	4¾ to 5	inches.
10/	20/	40/	50/	per ton extra.

Rounds only.

5¼ to 5½	5¾ to 6	6¼ to 6½	6¾ to 7	inches.
70/	90/	110/	130/	per ton extra.

Flats.

	⅛	3/16	¼	5/16	⅜ in thick.
1 inch wide	20/	10/	...	...	... per ton extra.
⅞ ,,	30/	20/	10/	10/	10/ ,,
¾ ,,	40/	30/	20/	10/	10/ ,,
⅝ ,,	50/	40/	30/	20/	20/ ,,
½ ,,	60/	50/	40/	30/	30/ ,,

Sash and Fancy Iron.—Rolls will be turned for unusual patterns if quantity required be not too small.

Tyre Iron.

From 3½ to 4 cwt. each .... 40/ per ton extra.
,, 4 ,, 5 ,, ... 80/ ,,
,, 5 ,, 6 ,, ... 120/ ,,
Bending .... 7/ ,,
Welding and blocking .... 70/ ,,

Wire Rods.—If wanted in long lengths, will be coiled up without extra charge.

Angle and Tee Iron.

For each ⅛ inch below 1½ × 1½ to ¾ × ¾ inch...... 10/ per ton extra.
,, ½ ,, above 8 united inches .... 10/ ,,
,, ½ ,, bulb above 7 do. .... 20/ ,,

Girder Iron.

For each ½ inch above 8½ united inches 20/ per ton extra.

Hoop Iron.

⅞	¾	⅝	½	inch wide.
20/	40/	80/	120/	per ton extra.

6 to 3¾ inches	not thinner than	No.	14 W. G.	ordinary gauge.
3½ ,, 2¼	,, ,,		15 ,,	,,
2 ,, 1⅝	,, ,,		17 ,,	,,
1½ ,, 1⅜	,, ,,		18 ,,	,,
1¼ ,, 1	,, ,,		19 ,,	,,
⅞ ,, ½	,, ,,		20 ,,	,,

For each gauge thinner, 10/ per ton extra.

Sheet Iron.

Doubles, No. 21 to 24 W. G. .... 30/ per ton above singles.
Latten, No. 25 ,, 27 ,, ... 60/ ,, ,,
Each gauge above No. 27 .... 20/ per ton extra.

STAFFORDSHIRE—*continued.*

Plates.

Above 4 cwt. to 5 cwt. per plate	....	20/	per ton extra.
,, 5 ,, 6 ,,	....	50/	,,
,, 6 ,, 6½ ,,	....	70/	,,
,, 6½ ,, 7 ,,	....	90/	,,
,, 24 feet superficial if under 4 cwt.	......	20/	,,
,, 15 ,, long	....	40/	,,
,, 4 ,, wide	....	40/	,,

NEWCASTLE AND MIDDLESBORO' IRON.

The ordinary sizes are from ½ to 3 inches round and square, and from 1 to 6 inches wide by ¼ to 1¼ inch thick.

Rounds and Squares.

$\frac{7}{16}$	$\frac{3}{8}$	$\frac{5}{16}$	$\frac{1}{4}$	$\frac{3}{16}$ inches.
10/	20/	30/	40/	70/ per ton extra.

For each ¼ inch above 3 inches 5/ per ton extra.

Flats.

	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	inch thick.
1 inch wide	20/	10/	...	...	...	per ton extra.
$\frac{7}{8}$,,	40/	30/	10/	10/	10/	,,
$\frac{3}{4}$,,	60/	30/	20/	10/	10/	,,
$\frac{5}{8}$,,	70/	40/	30/	30/	...	,,
$\frac{1}{2}$,,	90/	80/	60/	...	...	,,
Above 6 inches wide for each ½ inch					10/	,,

Tyre Iron.

For each ½ cwt. above 3 cwt. .... 10/ per ton extra.

Angle and Tee Iron.

For each ⅛ inch below 1½ to 1½ to ¾ × ¾............ 5/ per ton extra.
,, ½ ,, above 8 united inches .... 10/ ,,
,, ½ ,, bulb above 7 do. .... 10/ ,,

Girder Iron.

For each ½ above 8½ united inches 10/ per ton extra.

Hoop Iron.

⅞ inch wide not thinner than No. 19 W. G....... 10/ per ton extra.
¾ ,, ,, No. 20 ,, ... 30/ ,,
⅝ ,, ,, No. 20 ,, ... 80/ ,,
For each gauge thinner .... 20/ ,,

Sheet Iron.

Doubles, No. 21 to 24 W. G.......... 30/ per ton above singles.
Latten .... 60/ ,,

Plates.

¼ inch and thicker, for each ½ cwt. above 4 cwt.................. 10/ per ton extra.
¼ ,, ,, 2 inches wider than 4 feet .... 10/ ,,
¼ ,, more than 40 feet superficial, special agreement.
Thinner than ¼ to $\frac{3}{16}$ inch, for each 1 inch wider than 4 feet 20/ ,,
,, ¼ ,, $\frac{3}{16}$,, and more than 32 superficial feet, special agreement.
⅛ inch if 4 feet wide.. 20/ ,,
⅛ ,, above 4 feet wide or 28 feet superficial, special agreement.

Chequered Plates.

For each 1 inch wider than 30 to 39 inches .... 5/ per ton extra.
Above 8 feet long, special agreement.

YORKSHIRE IRON.

Ordinary Quality.

The ordinary sizes are from ½ to 3 inches round and square, and from 1 to 6 inches wide by ¼ to 1¼ inch thick.

Rounds and Squares.

$\frac{7}{16}$	$\frac{3}{8}$	$\frac{5}{16}$	$\frac{1}{4}$	$\frac{3}{16}$	inch.
10/	20/	30/	40/	80/	per ton extra.

3¼	3½	3¾	4	4¼	4½	4¾	5	5¼	5½	5¾	6	inches.
5/	10/	15/	20/	30/	40/	50	60/	70/	80/	90/	100/	per ton extra

Flats.

7 inches broad........................ 20/ per ton extra.
Above 7 do. .... 30/ ,,
⅞ inch wide by $\frac{1}{16}$ .... 10/ ,,
¾ ,, ... 20/ ,,
⅝ ,, ... 30/ ,,
½ ,, ... 40/ ,,

Tyre Iron.

4 cwt. to 5 cwt. each .... 40/ per ton extra.
5 ,, 6 ,, ... 90/ ,,
6 ,, 7 ,, ... 140/ ,,
7 ,, 8 ,, ... 180/ ,,
Welded and blocked .... 80/ ,,

Angle.

1¼ to 1½ inch by ¼ .... 10/ per ton extra.
1 ,, ⅞ ,, $\frac{3}{16}$.................. 10/ ,,
1 ,, ⅞ ,, ⅛ .... 20/ ,,
¾ ,, $\frac{3}{16}$.................. 20/ ,,
¾ ,, ⅛ .... 30/ ,,
Angle and Tee Iron above 8 united inches according to agreement.
,, above 25 feet to 30 feet long...... 10/ per ton extra.
Tee ,, 21 ,, long, special agreement.

Hoop Iron.

⅞ inch by 20 W. G. .... 20/ per ton extra.
¾ ,, 20 ,, ... 40/ ,,
⅝ ,, 20 ,, ... 80/ ,,
½ ,, 20 ,, ... 120/ ,,
Hoops under 1 inch wide 20/ extra for each gauge under 20 W. G.
,, cut to exact lengths or above 4 inches wide...... 10/ per ton extra.
,, above 4 inches to 6 inches wide..................... 10/ ,,
,, ,, 6 ,, wide for each inch.................. 10/ ,,

Plates.

Extras same as Staffordshire.

Superior Quality.

Rounds and Squares.

From 3 to 4 cwt. each bar............ 20/ per ton extra.
,, 4 ,, 5 ,, ... 40/ ,,
,, 5 ,, 6 ,, ... 60/ ,,
,, 6 ,, 7 ,, ... 100/ ,,
,, 7 ,, 8 ,, ... 140/ ,,
For each $\frac{1}{16}$ under $\frac{5}{8}$ inch .... 10/ ,,

YORKSHIRE—*continued.*

Flats.

For each $\frac{1}{8}$ inch less than 1 inch wide......... 10/ per ton extra.

Tyre Iron.

From $3\frac{1}{2}$ to 4 cwt. each...........	80/	per ton extra.
,, 4 ,, 5 ,, ...	160/	,,
,, 5 ,, 7 ,, ...	240/	,,
7 and above	320/	,,
Bending	7/6	,,
Welding and blocking	80/	,,

Plates.

From 3 to $3\frac{1}{2}$ cwt......................	60/	per ton extra.
,, $3\frac{1}{2}$,, 4 ,, ...	100/	,,
,, 4 ,, $4\frac{1}{2}$,, ...	160/	,,
,, $4\frac{1}{2}$,, 5 ,, ...	200/	,,
Above 5 ,, ...	300/	,,
Plates to sketch, or differing from a square form or regular taper	60/	,,

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Lowmoor or Bowling.

Rounds, Squares, and Flats.

From $2\frac{1}{2}$ to 3 cwt. each bar	10/	per ton extra.
,, 3 ,, 4 ,, ...	30/	,,
,, 4 ,, 5 ,, ...	50/	,,
,, 5 ,, 6 ,, ...	80/	,,
,, 6 ,, 7 ,, ...	120/	,,
,, 7 ,, 8 ,, ...	180/	,,
,, 8 ,, 9 ,, ...	280/	,,

Rounds.

$\underbrace{\tfrac{9}{16} \quad \tfrac{1}{2}}_{20/}$ $\quad \underbrace{\tfrac{7}{16} \quad \tfrac{3}{8}}_{40/}$ $\quad \underset{60/}{\tfrac{5}{16}}$ $\quad \underset{80/}{\tfrac{1}{4}}$ $\quad \underset{100/}{\tfrac{3}{16}}$ inch. per ton extra.

Squares.

$\underbrace{\tfrac{3}{16} \text{ to } \tfrac{7}{16}}_{20/}$ inch. per ton extra.

Flats.

Under $\underbrace{1 \times \tfrac{1}{4}}_{20/}$ inch. per ton extra.

Tyre Iron.

From $3\frac{1}{2}$ to 4 cwt. each..................	80/	per ton extra.
,, 4 ,, 5 ,, ...	160/	,,
,, 5 ,, 7 ,, ...	240/	,,
Above 7 ,, ...	320/	,,
If under 8 feet 6 inches long	40/	,,
Bending tyres	7/6	,,
Welding and blocking	80/	,,

Rivet Iron.

$\frac{9}{16}$ and $\frac{1}{2}$ inch................................	20/	per ton extra.
$\frac{7}{16}$,, $\frac{3}{8}$,, ...	40/	,,
$\frac{5}{16}$ inch....................................	60/	,,
$\frac{1}{4}$,, ...	80/	,,
$\frac{3}{16}$,, ...	100/	,,

YORKSHIRE—*continued.*

Hoop Iron.

7/8 to 3/4 inch broad	20/	per ton extra.
5/8 ,, 1/2 ,,	40/	,,

Plates.

From 2 1/2 to 3 cwt.	20/	per ton extra.
,, 3 ,, 3 1/2 ,,	60/	,,
,, 3 1/2 ,, 4 ,,	100/	,,
,, 4 ,, 4 1/2 ,,	160/	,,
,, 4 1/2 ,, 5 ,,	200/	,,
Above 5 ,,	300/	,,

Hammered and chequered plates, and all plates of irregular form, 60/ per ton extra.

WELSH IRON.

The ordinary sizes are from 5/8 to 3 inches round and square, and from 1 inch wide by 3/8 inch, and from 1 1/8 to 6 inches wide by 1/4 to 1 inch thick.

Rounds and Squares.

9/16	1/2	7/16	3/8	5/16	1/4	3/16	inches.
10/	10/	20/	30/	40/	50/	100/	per ton extra.

3 1/8 to 3 1/2	3 5/8 to 4	4 1/4 to 4 1/2	4 5/8 to 5	5 1/4 to 5 1/2	5 3/4 to 6 inches.	
10/	20/	30/	50/	60/	80/	per ton extra.

For lengths. Heavier than 6 cwt. per bar special agreement.

Flats.

	1/8	3/16	1/4	5/16	3/8	inch thick.
1 inch wide	30/	20/	10/	10/	...	per ton extra.
7/8 ,,	30/	20/	10/	10/	10/	,,
3/4 ,,	40/	30/	20/	20/	10/	,,
5/8 ,,	50/	40/	30/	30/	20/	,,
1/2 ,,	60/	50/	40/	40/	30/	,,

	Per ton extra.		Per ton extra.
3 1/4 to 4 inches by 2 1/2 to 3 inches	10/	7 1/4 to 8 inches by 3/16 to 5/16	30/
4 1/4 ,, 5 ,, 2 ,, 3 ,,	20/	7 1/4 ,, 8 ,, 3/8 ,, 1	20/
5 1/4 ,, 6 ,, 1 1/4 ,, 1 1/2 ,,	10/	7 1/4 ,, 8 ,, 1 1/8 ,, 2	30/
5 1/4 ,, 6 ,, 1 3/4 ,, 2 ,,	20/	9 ,, 3/8 ,, 2	50/
6 1/4 ,, 7 ,, 3/16 ,, 5/16 ,,	30/	10 ,, 3/8 ,, 2	50/
6 1/4 ,, 7 ,, 3/8 ,, 2 ,,	20/	12 ,, 3/8 ,, 2	60/

Tyre Iron.

From 3 1/2 to 4 cwt. each	40/	per ton extra.
,, 4 ,, 5 ,,	120/	,,
,, 5 ,, 7 ,,	200/	,,
7 cwt. and upwards	280/	,,

Angle and Tee Iron.

Above 7 and not exceeding 9 united inches	10/	per ton extra.
,, 9 ,, 10 ,,	30/	,,

Nail Rods.

000 or 9 W. G. or 9/64 inch square	10/	per ton extra.
0000 or 9 × 10 W. G.	20/	,,
1/8 inch square, equal to 9 × 11 W. G.	20/	,,
3/32 ,, ,, 9 × 12 ,,	20/	,,

Sheet Iron.

Doubles No. 21 to 24 W. G. inclusive	30/	per ton extra.
Latten ,, 25 ,, 27 ,,	60/	,,
,, 28	80/	,,
,, 29	100/	,,

WELSH—*continued.*

Sheet Iron—*continued.*

Above 3 feet wide and under 11 W. G. ...... 10/ to 40/ per ton extra.
,, 8 ,, long, special agreement.
Strips narrower than 12 inches .... 10/ ,,
Corrugated Sheets. Curving 20/ per ton extra.
Extras for gauge as above.

Plates.

Above 4 cwt. to 4½ cwt. .... 20/ per ton extra.
,, 4½ ,, 5 ,, ... 40/ ,,
,, 5 ,, special agreement.
,, 4 feet wide .... 40/ ,,
,, 12 ,, long, and not exceeding 15 feet 20/ ,,
,, 15 ,, ,, 18 ,, 40/ ,,
,, 18 ,, ,, 21 ,, 60/ ,,
Taper, circular, or other shapes not rectangular, according to sketch.
Strips narrower than 12 inches 10/ per ton extra.

SCOTCH IRON.

The ordinary sizes are from ⅜ to 3 inches round and square, and from 1¼ to 6 inches wide by 1¼ to 1 inch thick.

Rounds and Squares.

9/16	½	7/16	⅜	5/16	¼	3/16	inches.
10/	10/	20/	30/	40/	50/	80/	per ton extra.

3¼	3¾	4	4¼	4½	4¾	5	5¼	5½	6	inches.
$\underbrace{\quad\quad}_{10/}$		20/	30/	40/	50/	60/	70/	80/	100	per ton extra.

Flats.

	⅛	3/16	¼	5/16	⅜	½	⅝ inch thick.
1¼ to 6 inches wide	...	10/	...	...	...	...	...
1⅛ wide	30/	20/	20/	20/	...	...	...
1 ,, ...	40/	20/	20/	20/	...	...	...
⅞ ,, ...	40/	30/	20/	20/	10/	10/	10/
¾ ,, ...	50/	40/	30/	30/	20/	20/	20/
⅝ ,, ...	60/	50/	40/	40/	30/	30/	...
½ ,, ...	...	60/	50/	50/	40/	...	...
⅜ ,, ...	...	60/	50/	50/	...	...	...
6½ and 7 inches ...	...	20/	10/	10/	10/	10/	...
7½ inches	...	...	...	20/	20/	20/	...
8 ,, ...	...	...	...	30/	30/	30/	...

Tyre Iron.

From 3 to 4 cwt. each............ 30/ per ton extra.
,, 4 ,, 5 ,, ... 60/ ,,
,, 5 ,, 6 ,, ... 100/ ,,

Angle Iron.

⅞ inch by ⅞ inch... 20/ per ton extra.
¾ ,, ¾ ,, ... 30/ ,,
5 ,, 3½ ,, ... 10/ ,,
5½ ,, 3 ,, ... 10/ ,,

Tee Iron.

5 × 3 .... 20/ per ton extra.
6 × 4 .... 30/ ,,
4 × 4 .... 20/ ,,
5 × 5 .... 30/ ,,

Girder Iron.

6½ × ½ inch .... 10/ per ton extra.
7 × ½ ,, ... 20/ ,,
8 × ½ ,, ... 30/ ,,
9 × ½ ,, ... 40/ ,,
10 × ⅝ ,, ... 50/ ,,

SCOTCH—*continued.*

Hoop Iron.

7	inches to 2¼	inches wide,	if thinner than	15 W. G.	... 10/	per ton extra each gauge.
2	,, 1⅝	,,	,,	17 ,,	... 10/	,,
1½	,, 1⅜	,,	,,	18 ,,	... 10/	,,
1¼	,, 1	,,	,,	19 ,,	... 10/	,,
⅞	inch 20/	extra, and	if thinner than	20 ,,	... 20/	,,
¾	,, 40/	,,	,,	20 ,,	... 20/	,,
⅝	,, 80/	,,	,,	20 ,,	... 20/	,,
½	,, 120/	,,	,,	20 ,,	... 20/	,,

If cut to lengths 10/ per ton extra.

Sheet Iron.

No. 21 to 24 W. G. .... 30/ ... 20/ per ton extra each gauge thinner.
,, 25 ,, 27 ,, ... 60/ ... 20/ ,,
If under 12 inches wide 10/ per ton extra.

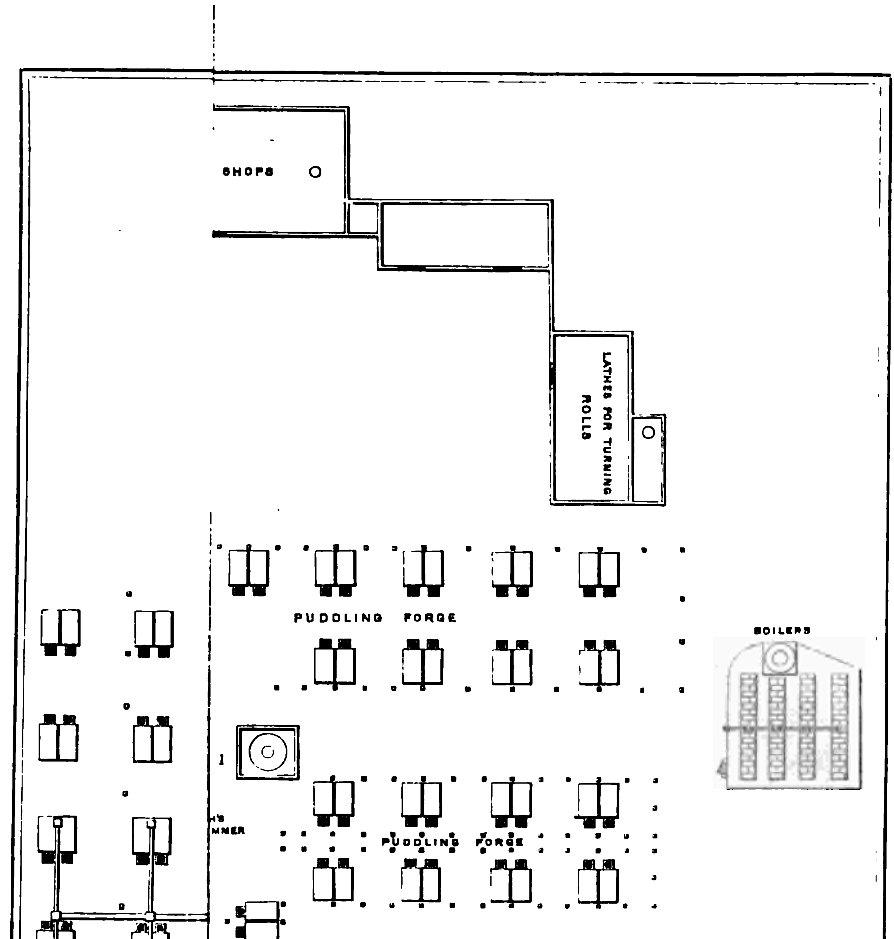
Plates.

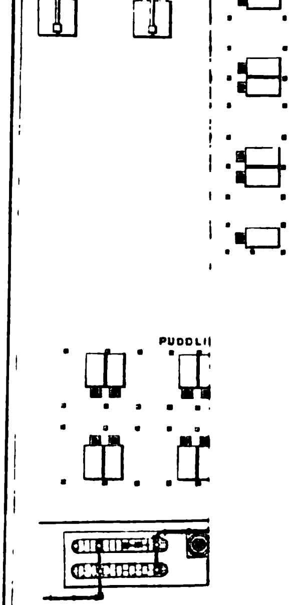
For each ½ cwt. above 4 cwt.	10/	per ton extra.
,, 1 foot ,, 15 feet long ...	10/	,,
If under 12 inches wide	10/	,,
Rounds	20/	,,

Other shapes per agreement.

All iron of unusual lengths, or cut to exact lengths or irregular shapes, will be charged extra according to agreement.

Some makers adopt a higher scale of extras than the above: when therefore special marks are ordered, the extras will be charged accordingly.





PLAN OF THE EBBW VALE FORGES AND MILLS.

REFERENCE TO FIGURES.

1.—A 43-inch condensing beam engine, 8 ft. stroke, making 20 strokes per minute, the rolls going 40 revolutions per min. The engine drives 3 trains of puddle rolls and 3 squeezers, and works for 50 furnaces.

2.—A 26½-in. high-pressure condensing beam engine, 5 ft. stroke, making 25 strokes per minute; rolls working direct. The engine drives one train of rolls and works a 4-ton helve-hammer. Steam got for engine and steam-hammer from the waste heat of the puddling-furnaces. 16 puddling-furnaces. The steam is at 40 lbs. pressure in the cylinder, and cut off at ¼ of the stroke.

3.—A 32-inch high-pressure beam engine, 6 ft. stroke, making 30 strokes per minute, driving 2 trains of rolls at 102 revolutions per minute.

4.—A 33-inch high-pressure beam engine, 8 ft. stroke, making 23 strokes per min., driving 3 trains of rolls making 78 revolutions per minute.

5.—An 18-in. horizontal high-pressure engine, 2 ft. 4 in. stroke, 50 strokes per minute, driving blooming rolls at 16 revolutions per minute.

6.—A 16-inch horizontal high-pressure engine, 3 ft. stroke, 50 strokes per minute, driving blooming rolls at 16 revolutions.

7.—A 19-inch horizontal high-pressure engine, 3 ft. stroke, 50 strokes per minute, driving blooming rolls at 16 revolutions. The blooms at each of these mills are lifted by a steam cylinder of 12 in. diameter.

8, 8.—Engines driving saws for sawing ends of rails off.

9.—A pair of 24-inch horizontal high-pressure engines, 4 ft. stroke, 30 strokes per minute, driving a train of rolls at 20 revolutions per minute to flatten the crop ends of rails.

10.—A high-pressure horizontal engine, 3 ft. stroke, 16 in. diameter, making about 40 strokes per minute, driving presses and punches for straightening and punching rails.

11, 11.—Two pairs of 10-inch horizontal engines, 18 inches stroke, making 80 strokes per minute, and driving 6 48-inch Lloyd's fans.

12, 12, 12, 12.—Shears for cutting up iron.

Place between pp. 760 and 761.

PLANS OF IRON-WORKS.

.he details of arrangement in iron-works must in a considerable ;ree depend on the nature of the locality in which they are situate. most works additions have from time to time been made; and the ın therefore is generally not such as would be adopted if the works ›re erected *de novo.* By way of illustration plans are presented of e Ebbw Vale Forges and Mills. The river Ebbw runs through the ılley, which is one of a series of similar valleys. On the right is wm Celyn, which in Welsh signifies the Holly Valley; and again, n the right of this valley is another, in which are the Blaenavon Iron- ʻorks. Almost all the iron-works of South Wales are readily ac- essible by railways from the village Crumlin, which may be con- ʻeniently selected for residence by persons proposing to visit these works.

DESCRIPTION OF THE GREAT MILL AT DOWLAIS.

For this description I am indebted to the manager, Mr. William Menelaus.

The large lithograph represents the machinery, and the smaller one the machinery and the arrangement of the furnaces.

The mill was built for the purpose of rolling beam and other iron of large sections and great length. The engines are powerful, and the machinery heavy in proportion.

For the foundations of the mill the ground was excavated until solid mine ground was reached; the excavation was filled with large rough blocks of limestone, the spaces between the blocks being filled with concrete; upon this foundation a floor of oak 6 in. thick was laid, and upon this floor the framing was placed without being attached in any way thereto.

The framing consists of a bottom and top girder of cast-iron, tied together by frames also of cast-iron; these frames or "crosses" fit into strong dove-tail jaws cast upon the girders; they are blocked with dry English oak and wedged with iron; there is no fitting, the castings being put together as they leave the foundry. Wherever practicable this method of fastening was adopted.

There are four lines of framing tied together at the ends by cross frames blocked and wedged as above. These lines of framing support the engines and machinery.

The cylinders, 45 in. in diameter and 10 ft. stroke, are fixed on bed-plates firmly secured in dove-tail jaws, and strongly bolted to the top of the framing. Fourteen columns attached by bolts and dove-tail jaws to the top girders support the framing for carrying the engine beams; these beams are of cast-iron of great strength. The pedestals are attached to the top framing by jaws and bolts, the covers are cast in a piece with the pedestal, and the top brasses keyed down upon the bearings.

The connecting rods are of oak, strapped with wrought-iron; at each end of the connecting rods a filling piece of cast-iron is inserted;

these filling pieces are firmly keyed against the ends of the timber for the purpose of preventing wear, and forming a solid bearing for the brasses.

The cranks are of cast-iron, blocked and wedged upon the shafts; the crank pins are of wrought-iron.

The cylinders have ordinary slide valves, with gridiron expansion valves on the back of the valve jackets; the valves are worked direct by cams on the crank shaft.

The engines are non-condensing, worked with steam of a pressure of 50 lbs. on the square inch.

The boilers are 6 in number, on the Cornish plan; the shells 45 ft. long, 7 ft. in diameter, and the tubes 4 ft. in diameter. The boilers are placed at a considerable distance from the engines, and upon a higher level; the steam is produced by the waste gases from the blast furnaces, which are situate about 700 yards from the boilers.

The crank-shaft is of cast-iron, hollow; the driving-wheel is 25 ft. in diameter, with 120 teeth, 8 in. in pitch and 2 ft. wide on the face. The centrepiece of this wheel is blocked and wedged upon the shaft; the arms are fastened by blocking and also by bolts; the ring is in 10 segments, attached to the arms simply by blocking and wedges.

The fly-shaft is of cast-iron, also hollow. The spur-wheel, 6 ft. diameter, is blocked on the middle of the shaft; and there are two fly-wheels, one fixed upon each end of the shaft, built up in the same way as the driving-wheel, with the exception of the rims, which are each in one piece, attached to the arms by dove-tail jaws and blocking. These wheels are 20 ft. diameter; the rims are 12 in. square.

Upon one end of the fly-shaft is the mill A. This mill is of ordinary construction, adapted for rolling heavy angle-iron, slabs, or rails: when making rails, the rolls make 100 revolutions per minute, and will turn out, if required, 80 tons in twelve hours.

For blooming the rail-piles there is a mill C with three rolls; there are carriages for raising and lowering the piles, worked from the end of the top roll. The workman has simply to turn the piles and push them into the grooves. The sawing and other machinery for this mill are of the ordinary construction, and driven from the large engines.

E is a flattening mill, where the crop ends of the rails as they are cut off are reduced to a rectangular shape, to fit them for piling. The blooming mill is driven by bevel gearing from the fly-shaft. There are also two heavy hammers DD, driven from the same line of shafting, for hammering rail-piles when this process is required. Upon the other end of the fly-shaft is a mill B, designed for rolling heavy girders and other difficult sections; the rolls are arranged as shown at F; the pile is first passed through the bottom pair of rolls, lifted in the ordinary way, and passed back through the top pair. These rolls, when making bars, which, from the thinness of section, require to be finished quickly, are run at 100 revolutions per minute; in this way H iron 10 to 12 in. wide can be rolled with ease up to 50 ft. long, and wider sections in proportionate lengths. This arrangement of rolls has the advantage of rolling backwards and forwards at a speed of 100 revolutions per

minute, and the bar requires to be moved through a small amount of space in passing from one groove to another.

With engines of ordinary power it would be impossible to roll iron of heavy section and great weight in this way; but in this mill the heaviest and longest bars are rolled with great ease, and without diminishing the speed of the engines.

The sawing machinery is driven from the large engines, the bench being moved by steam.

This mill is also employed in making heavy T rails.

There is a blooming mill at C′ for preparing the piles, as on the other side: the blooming mill shown in the drawing, however, has been removed, and an apparatus invented by Mr. Charles While of the Taff Vale Iron-works substituted, which consists of a pair of short horizontal rolls, with one groove suited to take in a bloom of 8 in. or 9 in. square; in front of this pair of rolls is another pair placed vertically, and in front of these again another pair, horizontal like the first; the diameters and grooves of these three pairs of rolls are adjusted so as to reduce the pile or bloom from 8 or 9 in. square to 6¼ or 7 in., being the proper size for the roughing rolls of the rail mill.

In this machine it is only necessary to put the pile from the carriage into the rolls, and it is delivered a finished bloom without any handling; this machine is well suited for blooming, where there is a long run of work of the same kind, as in a rail mill.

The straightening machines for finishing rails, the shears and punches for angle and other iron, are driven by the large engines.

STEEL.

The literature of steel is very extensive, the volumes and papers which have been written on the subject forming of themselves a library. Nevertheless, the science of the art of steel making is still in a very imperfect state, however advanced the art may be. The varieties of steel in commerce are exceedingly numerous, but the causes of difference are in many cases unknown, and the investigation of those causes is attended with great difficulty. Even on such an apparently simple point as the existence of nitrogen in steel, we have seen how discordant are the opinions of chemists of eminence. That the presence of this and certain other elements in minute proportions, especially silicon, sulphur, and phosphorus, does very sensibly modify the properties of steel may be regarded as well established; and the accurate quantitative determination of these elements, when combined or in association with a comparatively enormous mass of iron, is one of the most intricate problems of chemical analysis. It may, indeed, be doubted whether our present analytical methods suffice for its solution.

The principles of the methods by which steel is produced consist in the addition of carbon to malleable iron, the partial decarburization of cast-iron, and the addition of malleable iron to cast-iron; and, accordingly, I propose to describe the processes of making steel under these three heads.

PRODUCTION OF STEEL BY THE ADDITION OF CARBON TO MALLEABLE IRON.

In the direct Reduction of Iron-Ores at one Operation.

In the Catalan process.—In the description of this process previously given, the condition was specified which determined the formation of steel, or steely iron (*fer aciéreux*), namely, a relative increase in the proportion of charcoal, or, what is the same thing, a relative decrease in the proportion of ore. In this case the ore must first be reduced, and the resulting metallic iron afterwards carburized in the hearth by contact with incandescent charcoal. But in such a process uniform carburization could not be secured, and the lumps of metal obtained necessarily consisted of irregular mixtures of iron and steel.

In crucibles.—In 1791 a patent was granted to Samuel Lucas for making cast-steel by melting rich ores, such as the red hæmatite of Cumberland and Lancashire, in admixture with carbonaceous matters, charcoal, horn, bone-dust, or other cementing substances. It is directed that the operation should be conducted in air-tight melting-pots, that the ore should be in small pieces, and either mixed or interstratified

with the cementing matter.[1] The expression, other cementing substances, is one of remarkably wide acceptation.

Mr. David Mushet obtained a patent in 1800, in which, amongst other things, he claimed the production of cast-steel by melting in crucibles iron-ore, mixed with a suitable proportion of carbonaceous matter. I shall again have occasion to refer to this patent.[2]

In 1836 substantially the same process was again patented by John Isaac Hawkins. "Burnt mine," *i. e.*, roasted iron-ore, was broken into lumps of 3 lbs. or 4 lbs. weight; and each lump, imbedded in powdered charcoal, was subjected to a high temperature in crucibles during periods of 80, 76, 72 hours, etc.[3]

In converting furnaces.—In 1854 a patent was granted to Samuel Lucas, for "An improved Method of manufacturing Steel," which consisted essentially in interstratifying the bars of iron in an ordinary converting-furnace, to be hereafter described, with layers consisting of iron-ore in lumps about as large as walnuts, or any oxide of iron, such as iron-scale, etc., mixed with about equal quantities of animal or vegetable charcoal, and with oxide of manganese at the rate of about ½ lb. to 1 cwt. of ore, less or more manganese being used according to the degree of hardness required in the steel. It is directed that the bars of iron should not be allowed to touch the iron-ore, as the latter would adhere to them. The claim is also inserted in the specification for the conversion in a similar manner of iron-ore alone, without the presence of bar-iron.[4]

In 1856 William Edward Newton obtained a patent for "Improvements in the process of manufacturing steel, and carbonizing [sic] iron and the ores thereof," being a communication from abroad. The iron-ores are directed to be crushed or ground to the size of lumps of about 40 to the inch, mixed with charcoal or other carbonaceous matters, and, if requisite, also with suitable fluxes in alternate layers, and kept heated in a suitable cementing vessel[5] to whiteness during about 48 hours. When cold the ore is broken or crushed, and melted in crucibles to form cast-steel, or worked up in a furnace into spring-steel; but if found to be surcharged with carbon, they are to be puddled and hammered in the usual way.[6]

Experiments on the direct production of cast-steel from iron-ores in crucibles were made by Mr. E. Riley at the Dowlais Iron-works a few years ago. Excellent steel for chisels, etc., of which I have seen spemens, was occasionally obtained; but it was not found possible to ensure uniform results.

CARBURIZATION OF IRON AS A DISTINCT PROCESS.

In all the preceding methods it will be observed that steel was prepared from the ore at one operation. The process next to be con-

[1] A.D. 1791, April 18. No. 1869. Abridgments of Specifications, etc., *ante cit.* p. 14.

[2] A.D. 1800, Nov. 13. No. 2447. Abridgments.

[3] A.D. 1836, July 4. No. 7142.

[4] A.D. 1854, August 7th. No. 1730. Abridgments, *ante cit.* p. 176.

[5] This may mean either crucibles or a converting furnace.

[6] A.D. 1856, April 8. No. 851. Abridgments, *ante cit.* p. 222.

sidered involves two operations, one for the reduction of the ore, and the other for the carburization of the resulting iron.

CARBURIZATION OF PULVERULENT IRON.—CHENOT'S PROCESS.

The production of malleable iron by this process, which constitutes the first operation, has already been fully detailed; and it now only remains to describe the second operation, or the carburization of the reduced iron, which, it will be remembered, is obtained in the state of what is termed "metallic sponge." The sponge is intimately mixed with charcoal-powder or certain solid matters rich in carbon, such as common resin, the pulverization of which is facilitated by admixture with a little charcoal; or it may be impregnated by imbibition with liquid substances rich in carbon, such as wood-tar (coal-tar should be avoided on account of the sulphur which it generally contains), fatty matters, etc. The ground sponge is left immersed in the carburizing liquid until complete saturation occurs; and, when necessary, gentle heat may be applied to attenuate the liquid and so favour imbibition. The sponge is then drained, and afterwards torrefied in a close vessel during an hour. When fatty substances are used as carburizing agents, the sponge should be in lumps during impregnation, subsequently ground, and mixed with 75 % of unimpregnated sponge, as, otherwise, over-carburized and too hard steel would be produced. The sponge, thus prepared, is now compressed to $\frac{2}{5}$ of its original bulk, and at the same time moulded into little cylindrical pieces, which are melted in crucibles, exactly as in the usual method of fusing steel. The matrix of the ore swims on the top of the molten steel, and, immediately before casting, it is cooled by throwing a little sand into the crucible, and skimmed off. The charge is from 18 kil. to 25 kil. of prepared sponge per crucible, and the operation lasts on the average about 4 hours.[7]

According to Charrière, a well-known surgical instrument maker in Paris, steel produced by the Chenot process works well hot, but has neither the "body," the tenacity, nor the toughness (*résistance*) of first-class English steel. But Grateau, who espouses the cause of Chenot with perhaps more vigour than discretion, observes, with reference to the opinion of Charrière, that it "assigns to the Chenot steels a function different from that of the first English marks, without depriving them of their importance; they are very valuable for all purposes in which extra-superior qualities are not needed, and their price is moderate; for certain objects they will even be preferred, because they weld pretty easily, whilst the English steels do not weld at all."[8] The Chenot steels are declared by Grateau to be quite equal to the best French steels. This is, at least, an honest admission, and can neither be gratifying to the successors of Chenot, nor to the French metallurgist who predicted such a brilliant future for the process of Chenot.

Grateau presents elaborate computations of the "prix de revient," or cost of production of the Chenot steels; but as I know that in not a few instances "prix de revient" have proved fallacious, and

[7] Grateau, Revue Universelle, *ante cit.* part 4, 1859, p. 40 *et seq.*
[8] Op. cit. p. 59.

sadly detrimental to the interests of persons who have confided in them, I have become perhaps too distrustful with respect to their accuracy in all cases in which they have not been deduced from actual and *bonâ fide* balance-sheets. At the establishment at Clichy the cost of production of 1000 kil. (about 1 ton) of merchant steel is reported to be 1097·29 francs. This statement should inspire confidence, as it extends even to the fraction of a franc, or about 3*d.* on the ton; but the appearance of small fractions sometimes leads to an opposite result. Under ordinary average conditions, Grateau asserts that the maximum cost of production should not exceed 720 francs. He suggests that, in a metallurgical point of view, it would be both useful and interesting to represent the variations of the cost of production in different localities by diagrams, indicating the cost by ordinates, and the names of the works by arbitrary abscissæ. Definite curves would thus be traced, showing, with respect to the ore, fuel, pig-iron, iron, steel, etc., the variations of cost according to geographical position, and "the comparison of these tracings would furnish precious information."[9] They possibly might; yet the probability is that they would exhibit more of patient ingenuity than of substantial utility.

No apprehensions need be entertained as to the final triumph of the Chenot process; for, asks Grateau, "in presence of all the facts which we have exhibited, why not acknowledge that the method of fabricating cast-steel by means of iron sponge recommends itself, not only by its ingenious principle, but also by its having attained a degree of perfection which secures for it an industrial vitality? [The French word, which I have translated vitality, is 'viabilité.' The exact meaning would be rendered by the word 'liveableness,' or capability of living.] Resting upon serious and exact studies, pursued with indefatigable perseverance, the Chenot process has victoriously traversed all the critical phases of its elaboration; it has resisted attacks directed against it by those who were interested in obstructing its *début*, or who did not completely understand the fundamental principles which form its base. Is that saying that it has reached perfection? No, assuredly; and, after having developed what is remarkable in it, it is just to exhibit its weak sides."[1]

The truly defective part is admitted to be the fusion, the expense of which is very great. In spite of compression, the prepared sponge, weight for weight, occupies a larger volume than blister-steel melted in the usual way; so that, for crucibles of the same size, the charge is less in the case of the former than in that of the latter. But the temperature required in both cases is the same, to produce which the same amount of fuel must be consumed. Grateau in his concluding remarks informs us that Bessemer's process has with good reason been abandoned, an announcement which would be startling if it were true. It is to be hoped that this somewhat grandiloquent prophet will be more accurate in his predictions concerning Chenot, than in his declaration concerning Bessemer.

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[9] Op. cit. p. 58.

[1] Op. cit. p. 59.

Carburization of Bar-iron.

This is an old process, but little is known of its history. According to Beckmann there is no allusion to it in the writings of the ancients.[2] It was well described by Reaumur in 1722, in his admirable treatise on the Art of converting Bar-iron into Steel.[3] He made an extensive series of experiments on the subject, of which the records are worthy of being perused even at the present day. His work is illustrated with engravings, in which cementation, or, as they are termed in this country, converting furnaces, are represented similar in all essential respects to those which have so long been in operation at Sheffield, where, until recently, steel has almost exclusively been made by the process in question. Adventurous steel-making quacks, both native and foreign, with secret nostrums, abounded to such an extent in the days of Reaumur as to have rendered themselves a nuisance by their obtrusive impertinence. "The Court," he writes, "has been oppressed (*accablée*), especially during the last three or four years, by Frenchmen and foreigners of all countries, who, in the hope of making their fortunes, have presented themselves as having the true secret of converting iron into steel. But no fruit of their labours has been seen, and from the favours (*des grâces*) which have been accorded to several, those, who promised to change the irons of the kingdom into excellent steels, have almost been regarded as the searchers after the philosopher's stone."[4]

Converting furnace.[5]—For the drawings, from which the accompanying engravings have been executed, I am indebted to my friend Mr. E. F. Sanderson, of Sheffield, who has at all times shown the utmost willingness to assist me in my enquiries concerning steel, and from whom I have received much valuable information on the subject. The construction of the furnace is extremely simple, and will immediately be understood from the engravings. It consists essentially of an oblong rectangular case called chest or pot, of fire-brick, open at the top, and enclosed within an arched fire-brick chamber, with arched openings at each end, through which a man can enter. Underneath is a fire-place, from which, both at the sides and ends, proceed a series of vertical flues surrounding the exterior of the case, and opening into the arched space above. On each side of this space is a row of short chimneys, communicating with it at the spring of the arch. By this arrangement the chest may be uniformly heated to a pretty high temperature. The whole is contained within a hollow cone of brick-work, open at the top, just like an ordinary glass furnace. In practice two of these chests are built side by side, sufficient space being left for flues between the adjacent walls. The same letters in the different figures indicate similar parts. *a*, *a*. Converting chests. *b*, *b*. Fire-place. *c*, *c*. Ash-pit. *d*, *d*. Arched roof. *e*, *e*, etc. Flues.

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[2] A History of Inventions and Discoveries. 2nd ed. 1814. 4. p. 241.

[3] L'Art de Convertir le Fer forgé en Acier et l'Art d'Adoucir le Fer fondu. Paris, 4to. 1722.

[4] Op. cit. p. 6.

[5] An admirable model of a converting furnace may be seen in the Museum of Practical Geology. It was presented by Messrs. Naylor, Vickers, & Co., and previously appeared in the International Exhibition of 1851.

The iron to be converted is in the form of straight flat bars, generally about 3 in. broad and $\frac{5}{8}$ in. thick. In order to allow for expansion by heat, they must be somewhat shorter than the internal length of the chest. Charcoal, ground so as to pass through a riddle of from $\frac{1}{4}$ in. to $\frac{3}{8}$ in. mesh, is spread evenly over the bottom of each chest, and upon this bed of charcoal a layer of bars is placed longitudinally, flat-side downwards, and nearly touching each other; or, in order to allow for expansion by heat, the last bar in each course should not exactly fit. When the bars are too short to extend from

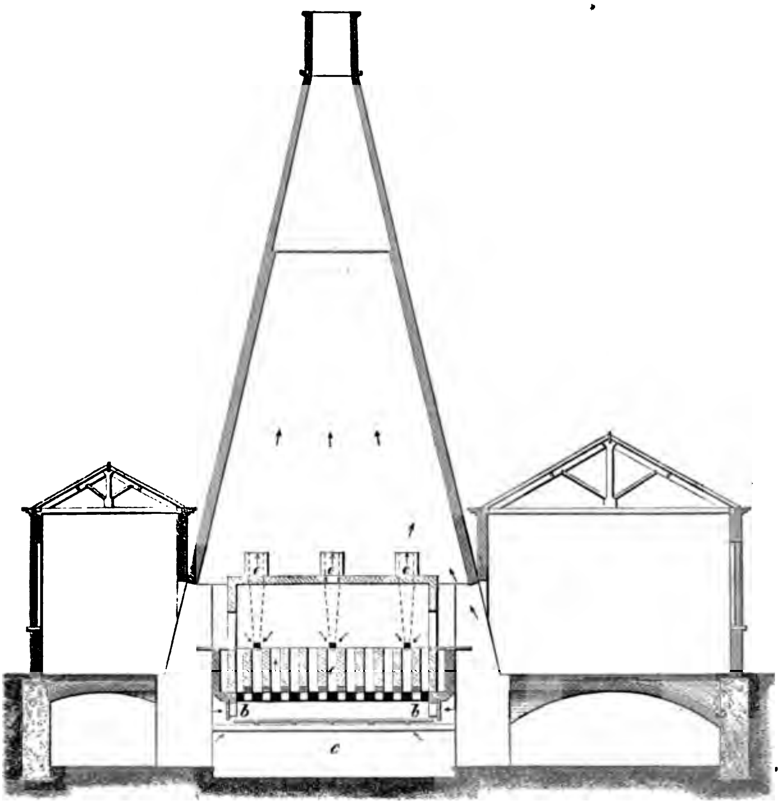

Fig. 208. Converting Furnace. Longitudinal Section.

one end to the other of the chest, the corresponding empty spaces are filled with short lengths of bars. This layer of bars is covered with a layer of charcoal about $\frac{1}{2}$ in. thick; then a second course of bars is laid, and so in succession, bars and charcoal in alternation, until the chests are filled, a thicker layer of charcoal being placed at the top; and this is plastered over with what is called "wheelswarf." It consists of finely divided silica, mixed with particles of steel, and is the substance produced by the wear of the siliceous grindstones, used in grinding articles of steel in the process of manufacture. By the action of heat,

it forms a compact covering, impervious to air, the particles of steel becoming converted into oxide of iron, which solders the particles of silica more or less firmly together. Clay, however, may be substituted for wheelswarf. The chests being fully charged, and everywhere made as impervious to air as possible, the entrances are closely stopped up

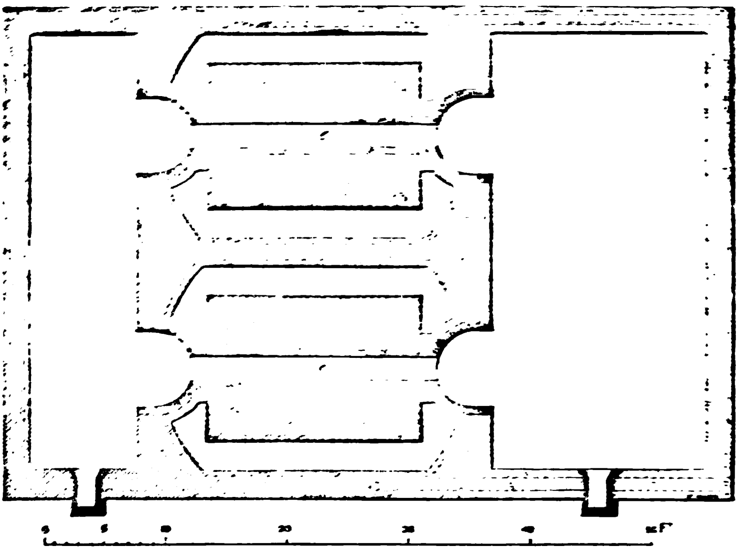

Fig. 209. Converting Furnace. Basement Plan.

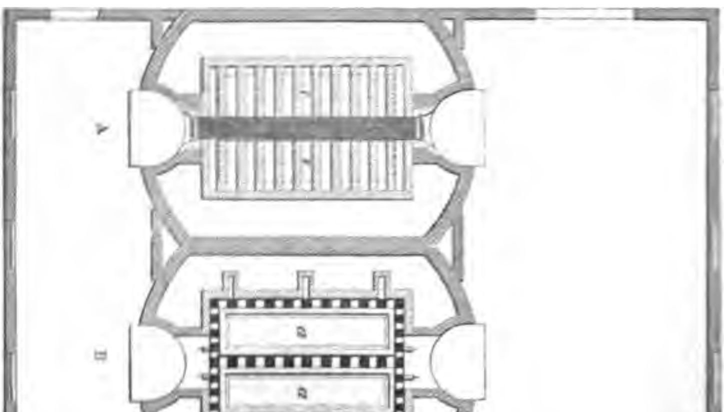

Fig. 210. Converting Furnace. Horizontal Section. A. Through the flues under the converting chest. B. Through the converting chest, showing the surrounding vertical flues.

As this woodcut is here placed the black lines are incorrect; but when held with the short side downwards they are correct, and it is intended to be looked at in this position with reference to fig. 211.

with bricks, and fire is made in the grates. The temperature should be evenly kept at glowing redness during periods of time which vary according to the degree of carburization desired. Steel for melting purposes requires from 9 to 10 days, for shearing 8 days, and for spring temper 7 days. Trial bars are previously inserted, with their ends protruding, so that they may be drawn out from time to time during the course of the operation through small apertures left purposely at the ends of the chest, and by the inspection of the fracture produced when cold, a judgment is formed as to the degree of con-

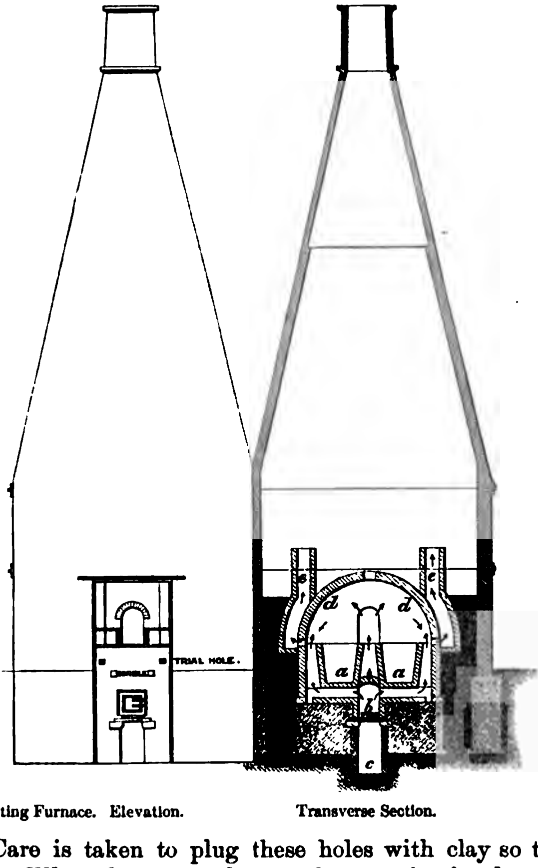

Fig. 211. Converting Furnace. Elevation. Transverse Section.

version. Care is taken to plug these holes with clay so that no air may enter. When the proper degree of conversion has been attained, the fire is withdrawn, and the furnace left to itself to cool, which generally requires several days, during which a further degree of carburization occurs. In three or four days after the removal of the fire, the cooling may be expedited by opening the man-holes, etc. As soon as a man can enter, the bars are taken out, broken across, and duly assorted according to the temper indicated by the appearance of their fractured surfaces.

The charge of a furnace of the dimensions usually preferred is from

[illegible] to [illegible] tons of bars. If the chests are too large, an equable temperature cannot be maintained throughout; and, consequently, the bars, especially towards the centre, will be carburized in a less degree than the rest.

In charging again, a portion of fresh charcoal is always mixed with the residual charcoal of the last "heat." In "drawing a heat" the charcoal is found to be partly in the state of soot-like dust and partly in its original form. The old charcoal is sifted to free it from dust, and then carefully washed. Thus prepared, and when dry, it is mixed intimately, measure by measure, with an equal bulk of fresh charcoal. This mixture has been found by experience to effect a more thorough and satisfactory conversion than fresh charcoal alone. The men say that fresh charcoal acts "too finely" on the iron; and when they are obliged to use it, the period of conversion is prolonged, as it is necessary to keep the furnace at a lower temperature than when the mixture abovementioned is employed.

Good white-ash coal is required in this process, which should not clinker, as in that case it would be impossible to secure uniformity of temperature. The stoking requires to be performed with much care.

The bars before and after conversion differ widely, not only in composition, but also in external characters. After conversion, their surfaces present blister-like protuberances, which vary much, both in number and dimensions. Some are not larger than peas, while others may exceed even 1 inch in diameter. They are hollow, exactly like blisters; and the bars are accordingly designated "blister-steel." Before conversion the bars were exceedingly tough, and the fracture, produced after nicking all round in the usual manner, was bright, crystalline, and of the characteristic bluish tinge of iron. After conversion they are brittle, and may be easily broken across; and the fracture is comparatively dull, shows more or less lamination, is still crystalline-granular, and, to my eye, has a slightly yellowish tinge. But these characteristic appearances can only be properly appreciated by actual inspection of unconverted and converted bars side by side.

With regard to the cause of the blisters, much diversity of opinion has been entertained. They appear to be due to internal local irregularities and gaseous expansion from within, while the iron was in a soft state from exposure to a high temperature. There is no doubt that all forged bars, for reasons previously assigned, contain more or less interposed basic silicate of iron irregularly diffused throughout. Now, what should be the effect of the contact of steel at a high temperature with particles of this silicate? Most probably, the reduction of part of the protoxide of iron, with the evolution of carbonic oxide; and, if this be so, then, it seems to me, the formation of the blisters may be satisfactorily accounted for. Admitting this explanation to be correct, a bar, which has been made from molten malleable iron, should not blister during cementation; and, should this prove to be the case, it would not be difficult to prepare such a bar with particles of cinder imbedded, and, by subsequently exposing it in a converting furnace, ascertain positively whether blisters would occur only in places corresponding to the cinder.

But another cause has been assigned for the blisters by the late Mr. T. H. Henry.[6] A bar of iron, previously to conversion, was found by him to contain 0·577 % of sulphur—a very large amount—and after conversion only 0·017 %, so that 97 % escaped during the process. Mr. Henry writes :—"I have no doubt that it was eliminated in the form of bisulphide of carbon, which is always formed when carbon and sulphur are brought in contact at a red heat; and a common method of its production used to be by heating iron-pyrites and charcoal to redness in close vessels. This substance is a highly volatile one; and its escape, in the form of vapour, will fully account for the blisters found in the steel. This curious fact opens up many points of interest, and throws, I think, considerable light on subjects which have hitherto been considered most obscure. It also shows how a quality of iron, containing a comparatively large amount of sulphur, may produce excellent steel when converted *in this manner*." Now, with reference to the illustration drawn from iron-pyrites, it should be remembered, that this sulphide, heated to redness *per se*, evolves sulphur, but there can be no such evolution in the case in question. The blisters must be due to the presence of something or other irregularly distributed through the iron; and Mr. Henry's hypothesis involves the assumption that this matter contained a comparatively large proportion of sulphur, which is not probable. The hypothesis of Mr. Henry might speedily be tested by experiment (vid. p. 34).

Carburization by Gaseous Compounds of Carbon.

In 1825 a patent was granted to Charles Macintosh, for converting malleable iron into steel by the action, at a white heat, of carburetted hydrogen, or gases charged with carbon.[7] I have already considered the principle of this method of cementation. The conversion, it is stated, was completed in a few hours; yet the process did not answer on the large scale, as "it was found impossible to keep the chambers in which the bars of iron were suspended, air-tight, at the very high temperature to which it was necessary to raise them."[8] In 1824 Professor Bismara, of Cremona, had made steel in a similar manner.[9]

Carburization by Fusing Compact Iron with Carbonaceous Matter.

The expression compact iron is in contradistinction to pulverulent iron, which is employed in Chenot's process. Of all the methods of making steel, this is, probably, the most ancient; for it is that which has been long practised by the Hindoos, with whom it may have originated.

Hindoo process.—It was accurately described as follows, in 1807, by Dr. Buchanan, the best writer on the subject of Indian arts and manufactures.[10] A wedge of iron, forming about a third part of one of the

[6] Letter to Mr. E. F. Sanderson, April 25, 1855.

[7] A.D. 1825, May 14. No. 5173. Abridgments, p. 30.

[8] Mushet, Papers on Iron and Steel, p. 671.

[9] Technolog. Encyklop. Prechtl. 15. p. 68.

[10] A Journey from Madras through the countries of Mysore, Canara, and Malabar. By Francis Buchanan, M.D. London, 1807, 2. p. 20. The process was witnessed on his journey from Sira to Seringapatam.

little lumps produced in an ordinary Hindoo iron furnace, is put into a conical unbaked clay crucible, of about the capacity of a pint, with the addition of 3 rupees' weight (531 grains) of the stem of *Cassia auriculata*, and two large smooth green leaves of a species of *Convolvulus* or *Ipomæa*. The crucible thus charged is closed at the mouth with a cap of unbaked clay well luted on, and then well dried near a fire. The furnace used is a little circular pit in the ground, somewhat dilated at the top. An earthen pipe, connected with two bellows, each consisting of a bullock's hide, and which are worked alternately, enters the fire-place at the bottom. A row of crucibles is first laid round the sloping mouth of the fire-place; then within these another row is placed; and the centre of the arch thus formed is occupied by a single crucible, making in all fifteen. The crucible in the outer row, opposite the nozzle of the bellows, is then taken out, and in its stead an empty crucible is placed horizontally, with its mouth directed inwards. This crucible can be readily drawn out and replaced, and the opening which it closes constitutes the fire-hole through which fuel is introduced. The fuel is charcoal, with which the fire-place is filled, and the arch of crucibles, charged as stated above, is covered over. The bellows are then plied during 4 hours, when the operation is completed. A new arch of crucibles is constructed, and the process goes on night and day; five sets, of 14 crucibles each, being every day worked off. On breaking open the crucibles the steel is found melted into the well-known conical cakes of wootz, which usually present a radiated wrinkling on their upper or flat surface, considered by Buchanan to indicate a tendency to crystallization. The cakes are surrounded by some vitrified matter. The steel in each crucible is reckoned by the workmen to weigh 1½ seer (this seer = 24 rupees), *i. e.* somewhat more than 2½ lbs.; but the cakes which Buchanan tried weighed very little more than 1 seer each. In some crucibles the fusion is not complete; in which case the steel is very inferior, and differs but little from common iron. The quantity of steel annually made in the district was about 152 cwts., of the value of about 2*l.* per cwt.

Mr. Josiah Marshall Heath, to whom I shall hereafter have occasion prominently to allude, published a short account of the method of making wootz, which agrees substantially with that of Buchanan, but differs slightly in minor details, as will be perceived by the following extracts from Heath's description.[1] The bars of iron produced by the Hindoos are cut into small pieces, to pack closely in the crucible. A number of these pieces, weighing from about ½ lb. to 2 lbs., as the mass of steel is required to be of greater or less weight, is then put into a crucible alone, with a tenth part, by weight, of dried wood chopped small, and the iron and wood are covered over with one or two green leaves; after which the mouth of the crucible is filled up

[1] Appendix to the Report on the Government Central Museum, Madras. By Edward Balfour, Esq. Madras, 1856, p. 1. Extracted from the Madras Journal of Literature and Science, 2. p. 184.

by a handful of tempered clay, rammed in close so as to exclude the air perfectly. The wood, which is always selected to furnish carbon to the iron, is that of *Cassia auriculata*, and the leaf used to cover the iron and wood is that of *Asclepias gigantea*, or, where that is not to be had, of *Convolvulus laurifolius*. As soon as the clay used to stop the mouths of the crucibles is dry, they are built up precisely as described by Buchanan; but Heath states that the blast is only kept up during 2½ hours instead of 4, and that the furnace contains from 20 to 24 crucibles instead of 14. When the fusion has been perfect, the top of the cake is covered with striæ, radiating from the centre, without any holes or rough projections on it; but when the fusion has been imperfect, the surface of the cake has a honeycombed appearance, and often contains projecting lumps of iron still in the malleable state.

The cakes of steel are prepared for being drawn into bars, by exposing them during several hours in a charcoal fire to a temperature just below their melting point. The fire is urged by bellows, and the blast is made to play upon the cakes while turned over before it. Hence it was inferred by Heath that in order to ensure the fusion of the contents of the crucible it was found necessary to employ a larger dose of carbon than sufficed to form the hardest steel, and that the excess was subsequently removed in the manner just described.

Dr. Pearson communicated, in 1795, an elaborate and, for the period, excellent paper on wootz, to the Royal Society.[a] He clearly established that it was only a particular variety of steel; but erroneously concluded that it was made directly from the ore. Mr. Stodart forged a piece of wootz for a penknife, at the "temperature of ignition in the dark. It received the requisite temper at 450° F. The edge was as fine and cut as well as the best steel knife." Wootz can only be forged at a low red heat, and even then not without much care; at a higher temperature it cracks or crumbles to pieces under the hammer. It is capable of acquiring great hardness. It was stated by Dr. Scott of Bombay, who communicated the specimens examined by Dr. Pearson, that wootz cannot be welded either with iron or steel.

The following analyses of wootz, before referred to, were made by the late Mr. T. H. Henry. The specimen operated upon came from the India House, and was in the shape of a bar 4 in. long and 1 in. square, weighing 4760 grains.

		Repetitions.
Carbon combined	1·333	1·340
Carbon uncombined	0·312	..
Silicon..........................	0·045	0·042
Sulphur	0·181	0·170
Arsenic	0·037	0·036
Iron by difference..........	98·092	
	100·000	

[a] Experiments and Observations to investigate the Nature of a kind of Steel manufactured at Bombay, and there called Wootz: with Remarks on the Properties and Composition of the different States of Iron. By George Pearson, M.D., F.R.S. Read June 11, 1795.

The specific gravity of this wootz was 7·727 at 62° F. Dr. Pearson published the following observations on the specific gravity of wootz.

1. Wootz	7·181
2. Another specimen of wootz	7·403
3. The same, forged	7·647
4. Another specimen, forged	7·503
5. Wootz which had been melted	7·200
6. Wootz which had been quenched while white hot...	7·166

Mushet's steel. Homogeneous metal.—A patent was granted in 1800 to David Mushet for a process of manufacturing cast-steel, etc., to which I have before referred.[3] The process consists in fusing malleable iron in the form of bar or scrap, or iron-ore, when sufficiently rich and pure, in crucibles with a proper percentage of carbonaceous matter. By varying the proportion of carbon, different qualities of steel may be made, smaller proportions producing softer steel. It is stated in the specification that "steel produced with any proportion of charcoal not exceeding $\frac{1}{100}$, will generally be found to possess every property necessary to its being cast into those shapes which require great elasticity, strength, and solidity; it will also be found generally capable of sustaining a white heat, and of being welded like malleable iron; and, indeed, as the proportion of charcoal or other carbonaceous matter is reduced, the qualities of the steel will be found to approach nearer to those of common malleable iron." Mr. Mushet, it is reported, disposed of this patent to a firm in Sheffield for the sum of 3000*l.* In his well-known treatise, the properties of the metal thus produced are accurately described as follows:[4]—"When iron is presented in fusion to $\frac{1}{140}$ or $\frac{1}{150}$ of its weight of charcoal, the resulting product occupies a kind of middle state betwixt malleable iron and steel. It then welds with facility, and [with proper precautions] may be joined to iron or steel, at a very high welding heat. Thus combined with carbon, it is still susceptible of hardening a little, but without any great alteration in the fracture. It possesses an uncommon degree of strength and tenacity [and is] capable of an exquisite degree of polish, arising from its complete solidity and the purity of fracture conveyed to it by fusion. When the dose of carbon is further diminished, and in the ratio of this diminution, the same steel or iron becomes more and more red-short, and less capable of cohesion under a welding heat, so that, when the proportion is reduced to $\frac{1}{500}$ part of the weight of the iron, the quality resulting is nearly analogous to the fusion of iron *per se*, or that obtained by the fusion of iron and earths."

In 1839 a patent was granted to William Vickers for the direct production of cast-steel by melting 100 lbs. of borings of iron, or wrought-iron scrap, with 3 lbs. of black oxide of manganese and 3 lbs. of best ground charcoal. The use of cast-iron scrap is also claimed, and the

[3] Manufacture of Cast-Steel, and an improved Coking Furnace. A.D. 1800, Nov. 13. No. 2447.

[4] Papers on Iron and Steel, 1840, p. 525.

proportions specified are 28 lbs. of the scrap, 2 lbs. 3 oz. of the oxide of manganese, and 3 lbs. of charcoal.[5]

Of late a variety of iron termed "homogeneous metal" has attracted attention. Numerous illustrations of this metal were shown at the International Exhibition, 1862, by Messrs. Shortridge, Howell, & Co., of Sheffield. The thin drawn tubes were particularly interesting, portions of which had been flattened and crumpled up, while cold, with apparently as much ease as caoutchouc, for which they might at first sight be readily mistaken, as, indeed, they have been. The metal possesses remarkable tenacity, and is, as its name implies, homogeneous. This latter quality is the result of fusion. A specimen of "homogeneous metal," used in the manufacture of an armour-plate, contained, as we have seen, 0·23 % of carbon. The relation between the iron and carbon (*i.e.* exclusive of 0·334 % of other matters, viz. silicon, sulphur, phosphorus, and manganese) is 99·206 : 0·230, or about $\frac{1}{430}$ of carbon. This is less than the smallest proportion of carbon specified by Mushet; but it must be remembered that the proportions which he did specify were those directed to be employed in the process of manufacture, and not those which had been found to exist in the steel when made. It is, moreover, certain that some of the carbon added must be burned by the air in the crucible; and it is further almost certain that what remains is not wholly taken up by the iron. However, the homogeneous metal is evidently a variety of cast-steel, containing a small proportion of carbon, and is intermediate in that as well as other respects between malleable iron and cast-steel. It has precisely the characters which Mushet ascribed to the metal manufactured by his process.

The expression "homogeneous metal" first occurs, if I mistake not, in the specification of a patent granted to Joseph Bennett Howell, of Sheffield, in 1856.[6] The descriptive part of the specification, which is very short, I present *in extenso.* "The novelty of my invention consists in using what is commonly known as the scale which falls off steel or iron during the process of hammering or rolling, in addition to the ingredients in common use for making cast-steel. I do not confine myself to the use of any given quantity of the said scale, as that must be determined by the particular temper of steel required for any special purpose. The object of this invention is to make a superior quality of cast-steel or homogeneous metal from the commoner kinds of iron." Anything more meagre and unsatisfactory in the way of directions for manufacture, I have never found in any specification; and I assert confidently that these directions are quite insufficient to enable a workman, even of skill, to practise Howell's process,—if process it deserves to be called. Moreover, the word temper is used in an ambiguous sense; as it might mean the special hardness of steel induced by the particular process or processes of tempering. I

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[5] A.D. 1839, June 25. No. 8129.

[6] Improvements in the Manufacture of Cast Steel. A.D. 1856, Oct. 9. No. 2369.

presume that the so-called "homogeneous metal" is indicated in this specification. Now, what is meant by the expression "ingredients in common use for making cast-steel"? Cast-steel is commonly made by melting converted bar-iron, *i.e.* blister-steel, *per se* in crucibles: but, surely, the word "ingredient" cannot apply to this blister-steel. If it do, then one effect of adding iron scale before or during the process of fusion, would be the decarburization of the steel in a greater or less degree, according to the proportion of iron-scale employed. If, on the other hand, the patentee mean the addition of iron-scale to certain substances, such as manganese containing carbon, etc., more or less decarburization will likewise take place, the carbon being oxidized and converted into carbonic oxide at the expense of the oxygen of the iron scale, with the reduction of an equivalent proportion of iron in the latter. But it is vain to conjecture what the patentee really does intend. Mr. Howell must know well that if iron-scale be allowed to come in direct contact with the substance of cast-steel pots at a high temperature, they will be inevitably much corroded, if not perforated; and that in order to prevent this, special precautions would be essential, such, for example, as the previous admixture of the iron-scale with carbonaceous or other matter, whereby the reduction of the oxide of iron composing the scale might be effected. These precautions should at least have appeared in the specification, but there is not even an allusion to them.

It is curious that Mushet's process, so far as relates to the use of malleable iron in the production of cast-steel, should in principle, and I may add even in practice too, be identical with that by which the Hindoos have from ancient times prepared their wootz. I cannot discover any essential difference between the two.

PRODUCTION OF STEEL BY THE PARTIAL DECARBURIZATION OF CAST-IRON.

The conversion of cast-iron into steel by partial decarburization may be effected in several ways; and of these are three of chief importance, namely, fining in a hearth with charcoal as the fuel, puddling in the reverberatory furnace, and the Bessemer process. The first is the ancient method, which is still extensively practised on the Continent, especially in Styria; the second is only of recent date, but has, nevertheless, made rapid progress; and the third is the most novel, and is certainly destined to play an important part in the world. If steel be regarded simply as iron carburized in degrees intermediate between malleable and cast-iron, then it is obvious that the latter during its conversion into the former in the processes of fining and puddling must pass through the state of steel. Accordingly, it is found that by suitably regulating and arresting the decarburizing action in these processes steel may be obtained instead of malleable iron.

Production of Steel by Fining in Hearths.

The hearth has essentially the same construction in all respects as those previously described for making malleable iron from cast-iron; and, indeed, in some localities iron and steel are alternately produced in the same hearth. However, the mode of conducting the process is not the same in both cases; or, in other words, steel is not obtained simply by checking the process of making malleable iron at a given stage. In the case of steel, the blast is generally less inclined, and the lump or cake of metal is kept covered with liquid cinder. This cinder plays an important part in the operation. It is supplied by the oxide formed in the reheating process, which is usually conducted in the same hearth as is used for making the steel, and by the addition of hammer-slag, etc. The liquidity of the cinder must be secured by the addition of silica, if necessary, so that the presence of much free oxide of iron may be avoided. Skilful manipulation is required; and especially that eye-knowledge, which can only be acquired by long experience. There are only a few special methods of producing steel in the charcoal finery, which have often been described, but by no one, as far as I am aware, so minutely as by Director Tunner, of Leoben, in Styria. This author admits the Styrian, the Carinthian, the Tyrolese, the Paal, and the Siegen processes as distinct; but I doubt whether the classification in every instance has a really philosophical foundation. Thus, it is stated that the peculiarity of the Tyrolese method consists in the fact that iron and steel are alternately produced in the same hearth, without any alteration either in the hearth itself or in the direction of the blast. Again, the Carinthian and Paal methods very closely resemble each other. The modifications, which may be necessary in the conduct of any of these methods, will in great measure be determined by the nature of the pig-iron operated upon. The steel is obtained in the form of a flat lump, which I will henceforth term *cake*, in contradistinction to *ball*, the term applied to the lump of malleable iron. Besides, it is a cake and not a ball, properly so called. The steel at first produced is always designated raw, or crude steel; and afterwards in the course of manufacture it becomes refined steel. It is not possible in the charcoal finery to produce raw-steel of uniform quality throughout. Some portions of the cake will be considerably less decarburized than others; and hence, an assortment of the steel, after more or less forging, is always made. However, no better steel in the world for special purposes has been made than in these finery methods. In the following descriptions I shall avail myself freely of the work of Tunner, condensing and translating literally as far as practicable.

Siegen raw-steel finery process. (*Siegener Rohstahlfrischarbeit.*)—For the following description of this process, I am indebted to my late assistant, Mr. Hochstätter, who has derived his information chiefly from personal observation.

The operation is conducted in a finery, similar in construction to charcoal fineries, in which malleable iron is produced. The sides of

the hearth are formed of cast-iron plates from 1 in. to 1¼ in. thick (*Zacken*); the front side, in which is a tap-hole for the cinder, is usually made of wrought-iron [illegible], forged from the same [illegible] charges [illegible] but with [illegible] instead of charcoal. The bottom of the hearth is constructed of pieces of fine-grained sandstone, put together as close as possible, the joints being filled in with powdered sandstone. Upon the quality of the sandstone much depends: it should neither be too coarse in grain nor have too great a tendency to crack or fly. Particularly good stone will last during the production of [illegible] or 10 cakes.[7] The twyer-plate, which is on the left (*Formzacken*), inclines from 12° to 15° inwards; the opposite plate (*[illegible]*), is either vertical or inclines a little outwards, so as to facilitate the drawing out of the finished product (*Schrei*); and the back plate (*Hinterzacken*) has, for the same reason, an inclination outwards. The hearth is contained within three brick walls, terminating in a short chimney above, the front side being open below, just as is represented in the engraving p. 582; it occupies only a fourth of the space under the chimney. On the front-plate is placed horizontally a thick cast-iron plate (*Herdgerte, Herdkuchen*), upon which are laid the pieces of pig-iron intended for the next heat. On the side-plate, facing the twyer, and the back-plate, are also horizontal cast-iron plates. A wrought-iron plate is suspended so as partly to cover the open space in front, and screen the workmen during the process. The dimensions of the hearth are as under: length 37 in., width 35 in., depth at the back and twyer sides 7½ in., and at the side facing the twyer 15 in. Above the twyer-plate is what is termed the "twyer bosh" (*Formbauch*), which is made of a mixture of loam and cow-dung, and in which is the opening for the twyer. The twyer, which is of wrought-iron, is midway over the twyer-plate, and projects several inches into the hearth; its inclination (*Stechen*) is varied according to the nature of the pig-iron to be operated upon; it is in the form of the segment of a circle, being 1½ in. broad at the base, which is flat, and ⅞ in. high at the middle of the base. The nozzle of the blast-pipe lies 1½ in. backwards from that of the twyer, in order to keep the latter cool by the blast of air through it.

The finished product or cake of the last heat (*Schrei*) having been taken out, and, according to its size, cut radially into 7 or 8 pieces, these are put on the plate on the right side of the hearth, except one, which is thrown behind the back-plate, where also the incandescent charcoal from the last heat has been accumulated. The bottom of the hearth is first repaired with little pieces of sandstone and a mixture of loam and water; and the tap-hole, which is on the same level, is plugged at the bottom for about ½ in. with loam, and on this is laid an iron plate 1½ in. thick; after which the upper and yet open part of the tap-hole is stopped up with a mixture of loam, ashes, and hammer-slag. Over the bottom is now spread a thin layer of hammer-slag, which, in contact with the sandstone underneath, forms silicate of

[7] Karsten, Eisenhüttenkunde, 4. p. 446.

protoxide of iron and produces an even surface, not liable to crack. This done, a layer about 1 in. thick of burning charcoal is spread over the bottom, and the blast-pipe adjusted in the twyer agreeably to the nature of the pig-iron used. A steep inclination tends to the production of malleable iron (the working condition of the furnace is then said to be *Gaargang*), and a less inclination to a contrary result (*Rohgang*). With grey pig-iron (*rohschmelziges*) and spiegeleisen, a steeper inclination is required than with white pig-iron (*gaarschmelziges*). At present (1859) at the Works, where the operation was witnessed, the pig-iron almost exclusively treated was spiegeleisen from the Stahlberg spathic ores; and with such pig-iron, the twyer was inclined from 10° to 15°, and the blast impinged upon the bottom of the hearth at the distance of from 3 in. to 4 in. from the opposite plate.

On the layer of ignited charcoal covering the bottom of the hearth, the first piece of pig-iron (*Heisse*), varying from 50 lbs. to 60 lbs. in weight and previously heated, and which was usually white pig-iron smelted partly with coke and partly with charcoal from a mixture of spathic and brown iron ores, is placed perpendicularly on edge at the side facing the twyer. The hearth is then $\frac{3}{4}$ filled with burning charcoal, and upon the top is placed the first piece or segment of the cake of the last operation, previously lying amongst the burning charcoal at the back, after which the hearth is filled up with fresh charcoal. The fire is allowed to burn for about $\frac{1}{4}$ of an hour without the blast, in order slowly to dry the repaired places. The other six or seven pieces of the last cake are laid round the hearth in order to receive a preparatory reheating. Thus the processes of reheating and fining take place in the same hearth. The blast is now let on. The pig-iron begins to fuse at the lower part, and is gradually melted down, forming a pasty mass. Rich cinder (*Gaarschlacke*) produced at the end of the heat preceding is thrown in. As soon as the molten pig-iron begins to become pasty, which is ascertained by feeling with a pointed iron rod (*Spiess*), a second piece of white pig-iron, weighing about 100 lbs., is introduced in the same way as the first; and afterwards four or five pieces of spiegeleisen, weighing also about 100 lbs. each, are successively charged in like manner. The weight of these pieces is not constant, but varies according to the judgment of the finer. If the molten metal is found to be too far advanced (*i. e.* too "gaar"), a larger piece of spiegeleisen is added. When cinder has accumulated to a certain extent in the hearth, it is tapped off. The poor cinder is very easily separated from the rich, as the former more quickly solidifies than the latter. In general the cinder is allowed to rise 2 in. or 3 in. over the cake in the hearth; and when the process is going on properly, the cinder which sticks to the finer's rod continues for some time white-hot after it is drawn out. The finer has to take care that, as the ball increases in size, the central portion, most exposed to the action of the blast, does not become over-fined. With every precaution, it is not possible to obtain a cake of uniform quality throughout; and while the outer portion of the cake consists of the right kind of steel, the central portion approximates to wrought-iron.

The outer portion in hammering yields what is termed "precious steel" (*Edelstahl*), and the inner portion an inferior quality of steel (*Mittelkür*); the latter will naturally increase, if the heat is not worked off in the right time, and under the most favourable conditions it amounts to about 26 % of the ball. The fining of one charge usually lasts from 7 to 8 hours. The degree of fining is indicated by the layer which adheres to the finer's rod, when the latter is put into the ball. This layer, called "white bird" (*weisses Vogel*), ought to be white-hot, and not to crack when struck with a hammer. Another indication is furnished by the appearance of the flame, which, when the right degree of fining is reached, from dull yellowish becomes whiter and brighter. But great experience is needed to enable the finer to judge correctly on this point.

When the cake is found to be properly fined, the blast-pipe is withdrawn, the charcoal removed from the hearth to the space at the back under the chimney, and the cake is uncovered and pulled out by means of a pair of tongs and iron bars. The tongs with the cake in their grasp are conveyed to the anvil by a crane, and the cake is there cut radially under the hammer into 7 or 8 pieces, a special tool (*Schröter*) being used for this purpose. As the central is less steely than the outer portion, it can be readily separated by thus cutting the cake radially into segments. At one finery four men are required, who change about, working two and two at a time, except when the cake is taken out, and then all are engaged. From 8 to 12 cakes are produced per week of 6 days; and from these on an average from 5000 lbs. to 7000 lbs. of steel bars, of which from 1600 lbs. to 2000 lbs. are of the inferior quality. The hammered out pieces are divided into the two qualities of metal composing the cake. This is effected by means of a heavy hammer upon the anvil, the best quality breaking off short. For 1000 lbs. Prussian of steel (about 1102·3 avoird.) are consumed from 20 to 22 "tonnen" of charcoal, *i. e.* from about 142 to 156 Prussian cubic feet, or from about 155 to 170 English cubic feet (1 Prussian "ton" = 7½ Prussian cubic feet, and 100 Prussian cubic feet = 109·184 English cubic feet). According to Karsten with very grey pig-iron the consumption of charcoal may amount to 40 Prussian cubic feet per centner of steel. The loss upon the pig-iron is from 26 % to 30 %. The raw-steel contains 0·3 % of copper, and from 0·31 % to 0·37 % of sulphur. The richer the spiegeleisen employed is in manganese, the harder is the steel obtained. During the process of fining, two kinds of cinder are produced, poor and rich, the former at the commencement and the latter towards the end. The poor cinder is very liquid, and the rich cinder is tougher, and on account of the large proportion of oxide of iron which it contains, is highly oxidizing. As may be readily conceived, it is easy to regulate the fining process by the addition of one or other of these cinders.

In the reheating process the pieces of the cake are successively heated to whiteness and turned several times, taken out of the fire, cleaned perfectly, and then subjected to a few blows under the hammer, when, if the fining is right, they must not crack at the edges.

Usually each piece must be reheated from 4 to 6 times, before it can be perfectly hammered out. The finished hammered out pieces are thrown while red-hot into running water. By this repeated hammering the steel increases proportionately in solidity and density. The hammer-head weighs 700 lbs., and makes from 100 to 106 strokes per minute.

The much greater inequality of the raw-steel made from grey pig-iron renders it necessary to conduct the processes of reheating and hammering with more care than in the case of raw-steel from pure spiegeleisen, which may be easily hammered out, and less frequently presents unsound and laminated places, defects which, in raw-steel from grey pig-iron, can only be remedied with the loss of much time in the process of hammering, repeated reheating being necessary. While only one hammer is required for a finery working on grey pig-iron, two will be necessary when good spiegeleisen is operated upon.

At some works, after the fining of the third piece of pig-iron, and when the fourth had been melted down, it was the practice to add old malleable iron, whereby the process was naturally expedited; and this was repeated after the melting down of the fifth and sixth pieces of pig-iron, so that frequently as much as the third part of a cake by weight was derived from malleable iron thus added. Special care was requisite in order to avoid great inequality in the cake.[8]

Styrian raw-steel process.—According to Tunner this process has the closest resemblance to the Styrian process of making malleable iron, so much so indeed that not only would strangers detect no difference, but even the finers sometimes unintentionally produce a lump of iron instead of steel, or the converse; and not unfrequently, at the same work, one finery is making steel, and another similar one iron. The hearth-bottom is of loam a few inches thick. The hearth is 23 in. long, 20 in. broad, and from 10 in. to 12 in. deep below the twyer.[9] The twyer-side inclines somewhat inwards, the wind and front side a little more outwards, and the side at the back also inclines outwards, but not so much. The twyer is midway between the front and back, and its axis is directed towards the centre of the hearth, or about 1 in. nearer the front. It inclines downwards from 15° to 17°, projects 4½ in., and is semicircular at the nozzle, which is 18 lines wide by 16 lines high. There is either one twyer with a constant blast, or two blowing alternately. White crystalline pig-iron is chiefly treated. The lower part of the bed is made of old brasque, and reaches to within 7 in. or 9 in. from the twyer; a few shovelfuls of pounded finery cinder are strewn over its surface; the hearth is then filled up to the twyer with sifted and slightly-wetted old brasque, and a little cavity is hollowed out in its surface. Every time after the removal of a cake (*Dachel*, *Tachel*) the hearth is thus prepared afresh down to the loam bottom, water being thrown on to cool it so as to enable the workman

[8] Karsten, *op. cit.* 4. p. 450.

[9] Austrian. I have not considered it worth while to reduce these measures into English, as the difference between the two cannot be of any practical moment.

to go in and stamp it down with the wooden soles of his shoes. The hearth is now filled with fresh charcoal, which is heaped up towards the back; the pieces of steel to be reheated are placed in ignited charcoal, a put in front of the twyer, the blast is let on, fresh charcoal is added, and over the top a few shovelfuls of pounded finery cinder are strewn. From [illegible] lbs. to [illegible] lbs. of pig-iron are required to make a cake, which is first cut crucially into four pieces, each of which is further divided into three equal pieces. Only three of these pieces are reheated at a time in the hearth, the others being kept hot in a separate little furnace, or otherwise. The pig-iron is in flat cakes 2 in. or 3 in. thick; and [illegible] lbs. of these are placed, with their flat side on the charcoal, in the hearth, so high that towards the wind-side they lie over the pieces of steel which are being reheated. It is necessary to heat the pig-iron very gradually, as otherwise it is very apt to crack and fly.

The quantity and quality of the pounded cinder strewn on is a matter of great importance, for the reheating process as well as for the production of the necessary bath of cinder, and one about which a judgment must be formed according to circumstances. As a rule in making steel, the cinder should be less rich and in greater quantity than when iron is made. At first the blast is only gently let on, so that the finery cinder added may not drop down too quickly through the charcoal, but may be well melted and form a more liquid bath. As soon as drops of molten cinder appear, which usually occurs in from 10 to 15 minutes, the blast is increased. In general, for the production of steel, the blast must be more gentle throughout from the commencement; and in this respect the process of making steel differs essentially from that of making iron. Moreover, as steel is more fusible than malleable iron, its reheating must be conducted at a much lower temperature; and as it is more difficult to draw out under the hammer, and is forged into smaller bars than iron, it requires more frequent reheating, and at a lower temperature. The "welding bottom" is formed partly from the oxidation of the pieces of the cake during the reheating process, and partly from the cinder expressly added. After the reheating process has been in operation about ¼ hour, the pig-iron is drawn a few inches forward; and in ½ hour this is repeated, the metal being allowed to sink deeper. It now begins to melt in drops. When only two of the pieces of steel undergoing reheating remain in the fire, the other cake of pig-iron is charged along with the rest of the metal to be melted down, in all from 30 lbs. to 60 lbs., upon the wind-side on the top of the charcoal, so as to become gradually heated. The cake of pig-iron is afterwards held with tongs above the twyer; and after the termination of the reheating process, which seldom exceeds 2 hours from the commencement, the cake, now red-hot, is held edgewise towards the twyer.

When all goes on properly, the molten metal should, on sounding with an iron rod, be even, more or less hard and slippery, but not sticky, and constantly covered with a layer, some inches thick, of a

liquid cinder. Too highly decarburized, fine-grained, white pig-iron[1] is unsuitable for this process; and one amongst other reasons alleged is, that in consequence of the more gentle blast it does not, when molten, spread properly over the bottom. The cinder is never tapped off during the reheating stage, except when special conditions render it necessary, such as the bed being too deep, or the formation of the molten metal "bottom" being retarded. Very generally cinder is first let out at the end of the reheating stage, and once or twice afterwards during the melting-down stage. The pressure of the blast must be regulated according to circumstances; but in making steel it seldom exceeds that of a column of water of from 10 in. to 15 in. high. In the regular course of working, the pig-iron should, previously to and during its melting down before the blast, acquire nearly the right degree of decarburization, its conversion into steel being completed under the molten cinder, of which the quality must be such as to prevent decarburization beyond the proper amount. The molten metal should never rise up to the twyer, as it would then be too much exposed to the blast, and consequently become too much decarburized. As soon as the hearth is filled with molten metal to within 1 in. or 2 in. below the twyer, the fining should be quickly brought to a conclusion. The time which elapses between the production of one steel cake and another is 3½ or 4 hours. The steel is forged into bars 1 in. thick, and 1½ in. broad. They are afterwards hardened, broken into pieces from ½ ft. to 2 ft. long, examined as to their fracture, and assorted accordingly.

The products are as under:—

1. *Meisselstahl* (Chisel steel), occasionally termed *Münz-* or *Rosenstahl* (Rose steel).—It is mostly in pieces from 4 in. to 12 in. long; the fracture is clean and conchoidal, has a uniform dull grain, and usually shows a rose. It is commonly packed in boxes, and is the dearest kind of unfaggoted Styrian steel.

2. *Edelstahl* or *Rohstahl* (Precious or Raw steel).—It is in pieces from ½ ft. to 2 ft. long; the fracture is clean; but no attention is paid to very small, white veins, or somewhat lighter spots in the fracture, accompanied with unsound places or scales on the surface. It is for the most part employed in making faggoted steel.

3. *Mockstahl*, *Halbstahl* (Half-steel), or *Rückenzeug*.—It is difficult to break. It contains intermixed iron, which appears on the fractured surface as well-defined veins, or as coarse, light, very bright grains. It is partly employed for inferior descriptions of faggoted steel, chiefly for the outer layers on the pile, and is partly sold for forging into scythes.

4. *Rohmittelzeug*.—It is used for inferior kinds of faggoted steel.

5. *Hammereisen* (Hammer-iron).—It is in pieces which can hardly be broken, and is hard iron rather than steel. It is applied to various purposes.

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[1] "Weiche Flossen." The adjective soft here used might greatly mislead. It is derived, not from the quality of the pig-iron, but from a technical expression of the German finers, "weiches Gang," which is used to indicate that the metal quickly "comes to nature." Tunner, 1. p. 12.

6. *Abfälle*, or *Refudi* (waste pieces).—They are run down again in the finery, but not unfrequently they are worked up into inferior descriptions of steel.

The best Styrian scythes, which are highly renowned, are made from the best qualities of steel, which the makers obtain from various steel-makers. They can thus make a proper selection—an advantage of which, according to Tunner, they cannot easily be deprived by foreign manufacturers, notwithstanding the latter may procure their steel from Styria. The Styrian scythes attracted great attention at the International Exhibition of 1862.

The production in a steel-work with two closed fineries, heated with blast at 150° R. (364·5° F.), and attended by 4 workmen, amounts to about 10 centners in 15 or 16 hours; and during this period 8 cakes are made, and all are forged into bars. The loss ranges between 9% and 10%. In open fineries the consumption of pine charcoal of the worst quality, inclusive of all waste, is from 34 to 35 cubic feet per centner; but with proper economy 30 cubic feet are quite sufficient. In closed fineries, with hot-blast, it is from 22 to 25 cubic feet. From 100 centners of pig-iron, at the present day, frequently 85 of raw and 5 of *mock* steel are produced, the loss being 9·3%. Formerly 100 centners of pig-iron yielded only 60 of raw steel, inclusive of Chisel-steel, 20 of *mock*, 6 of Hammer-iron, and 4 of *Rohmittelzeug*, the loss being 10%.

Carinthian raw-steel process (*Die kärntnerische Rohstahlarbeit*).—The following account of this process is derived from the description of it by Tunner.[a] It is conducted in a charcoal finery, resembling in all essential particulars those which have previously been described for the production of malleable iron. The hearth is from 22 in. to 23 in. long, and from 23 in. to 24 in. broad (Austrian measures, which I have not considered it necessary to reduce into English). The depth below the twyer to the hearth-bottom is from 11 in. to 13 in., and to the working bed of stamped charcoal, etc., from 7 in. to 9 in. The sides of the hearth are, as usual, formed of four cast-iron plates, which are called "stones." The twyer plate is about 3 in. lower than the other three plates. The height of the plate facing the twyer is a matter of importance; because, in the operation of fining, the pig-iron to be melted down lies upon this plate, and the horizontal plate at the same level on the side of it, so that the metal in melting may drop from a greater height, and its fining be thereby promoted. On this account the height of this plate may be varied, and extend from 2½ to 5 in. above the twyer-plate.

The nozzle of the twyer is usually circular, from 16 to 17 lines in diameter, and projects from 3½ in. to 4½ in. over the twyer-plate. The twyer inclines from 10° to 16°, with its axis directed towards the middle of the hearth. There are either two blast-pipes or only one, which

[a] Stabeisen-und-Stahlbereitung. 2. p. 250 *et seq.* I have greatly abbreviated his description, which abounds in the minutest details of manipulation: and, as far as practicable, I have translated literally.

in both cases are from 15 to 16 lines in diameter at the nozzle, and which lie back from 4 in. to 4½ in. from the nozzle of the twyer. The ordinary pressure of the blast is equal to a column of water of from 15 in. to 16 in.

The pig-iron treated is in two forms, viz. pigs and in round plates (*Blatteln:* see p. 611). The first is more or less mottled, seldom grey, and is previously refined. The second, through quenching with water, is in the state of crystalline white-iron, and is directly used in that state. The refining of the first is generally conducted in the steel finery itself, after the conclusion of the fining, the hearth being cleaned and made ready for the purpose; but at some works it is effected in a separate furnace. The pieces of refined iron (*Hartzerrennlöden*) should be tolerably smooth on their upper surface, and also on the under surface, which, however, presents numerous round depressions; they should be from ½ in. to 1 in. thick, with a radiated and only slightly porous fracture.

In a fresh built or newly repaired hearth, the preparation of the working bed, which consists of small charcoal mixed with ashes and cinder, requires the greatest care, as the success of the process greatly depends upon its solidity, which should be such that it cannot be penetrated by the finger—even when much effort is used,—and offers considerable resistance to a pointed iron rod. A basket of charcoal is thrown into the empty hearth, ignited, and allowed to burn away to half its bulk, when, along with the ashes produced, it is stamped solidly together. Upon this is spread a layer, 1½ in. thick, of old sifted brasque, and another charcoal fire is made over it as in the first instance. After the lapse of some hours the bed is stamped down, covered with old brasque, a charcoal fire made on the top, and the same process as above described repeated until the bed is raised to the height of 7 in. below the twyer. It is only possible by this means to produce a bed sufficiently solid, and, at the same time, bad conductor of heat. At each stamping the bed is raised about 1 in. higher, and about 100 blows are given. When the hearth is cold it must be heated, previously to working, during several hours, care being taken to prepare or renew the bed according to the foregoing directions.

The Carinthian process consists of three stages, which will now be described in order.

The hearth being filled with ignited charcoal, usually from 40 lbs. to 70 lbs. of fresh pig-iron, consisting of the thick edges of the round plates (*Blatteln*) and bottom lumps (*Könige*), previously lying on the wind-side, *i. e.* facing the twyer, are melted down with the addition of cinder; which requires from ½ to ¾ hour. A layer of thick molten metal is thus produced, termed "Sauer;" and simultaneously with its formation, the welding (*Abschweissen*) of the two halves (*Deule*) into which the cake (*Cotta*) of the last heat has been cut, is commenced and continued until both are worked into blooms. One of the *deuls* is put with its cut surface upwards, and with the opposite side or bottom between the twyer and the pieces of pig-iron in the hearth; whilst the other *deul*, with the bottom directed towards the hearth, is laid so as to form a

continuation of the wind-side of the hearth, in order that the charcoal afterwards heaped up higher on this side may be held together, and that the *deul* itself may receive a preparatory heating. The *deul* lying free before the twyer must be raised up from time to time, and not be allowed to sink down through the charcoal to the bottom.

In this stage the pig-iron should be rapidly melted down and brought into a semi-fined pasty state, which is induced by the decarburizing action of the cinder, and especially of the oxide of iron which drops off the *deul*. When the *sauer* attains this condition either too soon or too late, or when it is over-fined, the course of working is deranged. In the choice of the quality and quantity of pig-iron to form the *sauer*, the nature of the *deul* should be taken into account. The softer and larger the *deuls* the more fined will be the *sauer*, which, in that case, should therefore be present in greater quantity.

The object of the last manipulation is to clean the surface of the *deul* and remove the more ferriferous outer skin, which occurs especially on the bottom side; and, at the same time, to heat it sufficiently to allow of its being forged at one end into a prismatic piece 3 in. square, by which it may be easily grasped by tongs. As soon as the *deul* becomes heated to the welding point on the under side, it is raised up and turned with this side uppermost. Thereupon the softened and loosened edges are detached with a strong little shovel, or otherwise. This manipulation with the first *deul* is continued until, to the extent of half its length, its surface appears everywhere clean, when it is taken out and forged. The other *deul* is similarly treated. The duration of this first stage of the process is usually 1½ hour. At its conclusion the blast is stopped, the charcoal is removed from the hearth and put at the back, and the layer of cinder covering the *sauer* is thus laid bare.

The superficial solid crust of cinder being taken off, the *sauer* is broken up on all sides and piled into a little heap in the middle of the bed (*Aufrichten*); and if the process has been properly conducted, the *sauer* will be in a pasty state, and this manipulation quickly performed. Old brasque is strewed round the sides of the hearth, the charcoal previously removed put back into the hearth, the blast let on, and fresh charcoal added; and the last forged still red-hot piece is placed, with the bottom side undermost, in front of the twyer, whilst the first forged piece, now nearly cold, is laid on the wind-side to be reheated. In this second stage fining takes place, and, at the same time, the reheating of the pieces to be further forged is carried on. If the *sauer* is found to be too liquid, rich cinder, such as hammer-slag, must be stirred in; if so far advanced that, in the piling up process, it only admits of being broken into large pieces, fresh pig-iron (*Blattel*) must be added and melted down.

By the action of the blast on the piled-up loose mass of metal in the hearth, the upper part is fined, while the bottom is again melted down, forming a fresh *sauer*; and this, by suitable management, must be maintained during the whole of the following period, and, after the raising of the cake from the bed, must again become visible. It is only when molten pig-iron, highly decarburized, and "of a soft quality," exists

under the cake, that it may be concluded with certainty that the cake, at least on its under side, consists of perfectly hard steel. If this *sauer*, for want of the requisite heat, solidifies on the bed, the under side of the cake will not be steel, but pig iron.

After the completion of the piling-up process, the unforged half of the *deul* is heated from ½ to ¾ hour, and further manipulated, as in the first instance, and during this period the piled-up *sauer* sinks into a cake uniform and even on the surface, which is sounded with an iron rod, while the *deul* is out of the hearth and being forged. The cake should extend evenly over the bed, and be covered with a layer of cinder from 2 in. to 2½ in. thick. When it has increased so as to reach within about 1 in. of the twyer, the process is completed; the blast must then be stopped, the cinder tapped off, the charcoal removed from the hearth, and the cake exposed, upon the upper surface of which a little liquid cinder always remains. According as the cake appears more or less hard, it is left thus bare to cool during a longer or shorter time, the cinder which solidifies on its surface being removed at intervals. When it is considered to be sufficiently cool, which usually occurs in about from 10 to 15 minutes, the residual cinder, which is always solidified by pouring water over it, is taken off, the cake is raised, placed upon two iron bars laid across the hearth, and the adherent semi-solid *sauer* knocked off, dropping into *sauer* remaining in the hearth. It is afterwards taken to the hammer and divided. Never more than 3, and often only 2 cakes, are made without intermission. An interval of 6 or 8 hours then occurs, during which the hearth is kept heated with large pieces of charcoal. There is much uncertainty in judging of the quality of the steel from the external appearance of a cake. The cake is cut transversely from front to back as it lay in the hearth; and hence the pieces are named twyer-side and wind-side pieces. There is generally more difference in the quality of the metal in these two parts of a cake than in those corresponding to the back and front sides; and, consequently, by cutting in the direction stated above, greater uniformity in the quality of the finished steel is secured. The steel from the twyer-side piece is likely to be softer than that from the wind-side piece, as it is more exposed to decarburization. The hammer employed is small, and often scarcely gives 120 blows per minute, which is a radical defect in this process. A heat lasts from 5 to 6 hours; and during this period it is frequently not possible to forge all the steel produced in a previous heat. The steel is assorted according to its quality. The chief variety is known as *Brescian* steel, *Kölberlstahl*, or *Münzkölberlstahl*, and only the hardest should be selected for this. It is in small rods, weighing 5 lbs. or 6 lbs., and from ½ in. to ¾ in. square. The other varieties are known as *Tannenbaumstahl*, long or short,—*Stuckstahl*, great and small,—*Mockstahl*,—and *Refudi*, or waste steel, which is unsuitable for any purpose.

Three workmen are required,—a master-man, "a heater," and "a water-thrower." Each man has 8 or 10 hours' rest daily. The average weekly make of a Carinthian-steel finery is from 30 to 35 centners. The consumption of charcoal (*Fichtenkohle*) is from 40 to 50 cubic feet

for 100 lbs. of merchant steel. The consumption of refined pig-iron and crude pig-iron in the form of "blatteln" is in the ratio of from 3 : 1 to 2 : 1. The loss is from 20% to 30%, about 25% being the average. About ¾ of the raw steel produced should by good work be pure steel, and the rest more or less of the nature of malleable iron. The Carinthian steel is generally harder and more uniform than the Styrian.

The forging of Brescian steel is effected under hammers weighing from 1½ to 2 centners, seldom falling more than 10 in., and giving more than 200 blows per minute. Brescian steel is nearly always in the form of bars from ½ in. to ¾ in. square, from 4 ft. to 5 ft. long, and numbered 00, 0, 1, 2, 3, 4, 5, 6, 7, 8. The first production of this and similar sorts of steel took place without doubt in the province of Brescia; and formerly in the town of Brescia were manufactured the various kinds of celebrated Brescian steel-wares.

Paal steel process.[3]—This process is conducted at Prince Schwarzenberg's Works in Murau, Styria, which have been in existence nearly 200 years. According to Hermann, it was introduced by workmen from Crain (Carniola) in 1660.[4] It is very similar to the so-called Carinthian process, and it will only be requisite to indicate the points in which it differs from that process. From 200 lbs. to 250 lbs. of pig-iron are melted down to form *sauer*; and the 8 pieces, into which the 2 cakes obtained the day preceding have been cut, are taken up one after another with tongs, reheated in the hearth, dipped in the molten metal, and kept immersed for some time,—whereby they are stated to acquire hardness and tenacity,—then taken out, freed from the raw and loosely-adherent superficial crusts, and hammered, one end being forged into a 4-sided piece, which may be conveniently held by the tongs. When all the pieces have been successively treated in this manner, the cake is made. The *sauer* is examined, and if found to be already hard and steel-like, the formation of the cake is completed; but if, on the contrary, it is still too liquid, it is subjected to a "boiling" process. Charcoal is removed from the hearth, the blast is stopped, rich cinder, such as hammer-slag, is added, and is stirred well into the molten mass with a wooden rod until it begins to become hard, when the charcoal is put back into the hearth, and the melting down of the materials of the charge (refined metal and *blatteln*) is continued until the cake has become sufficiently heavy. The blast is then shut off, and the cake conveyed under the hammer and cut into 4 pieces. This first lump weighs from 2½ to 3 centners, and there remains in the hearth a bath of metal or *sauer*. Pig-iron, almost grey, is added to this, and melted down with the addition of hammer-slag, etc., so that the molten product is not very liquid. The four pieces of the day preceding are now divided into *tajoli*, and these again into pieces (*Köllbchen*), about 12 in. long, 2 in. broad, and 1½ in. thick, which

[3] Karsten, Eisenhüttenkunde, 4. p. 462. The style of Karsten is so lucid, and his arrangement so methodical, that it is a great relief to read his descriptions of processes, after the descriptions of some other German writers on Metallurgy. Paal is the old local name of the district.

[4] Karsten, ibid. p. 468.

are plunged while still red-hot into water, then broken, and afterwards forged into merchantable articles. After the completion of the forging of the cake of the previous day, fresh pig-iron is added, and the formation of the second cake proceeded with.

After the removal of the second cake, water is thrown upon the molten metal remaining in the hearth, and the solidified crust taken off, and this is done until 2 or 3 such crusts (*Böden*, and the operation is termed *Bodenheben*) are obtained. It is this metal and the "blatteln" which constitute the materials of the charge. The time required in this process is as follows.

For the first cake—

Melting down the charge	3 hours.
Dipping in the *sauer* and forging	4 ,,
Making the cake	5 to 6 ,,
Total	12 to 13 hours.

For the second cake—

Melting down the charge	2 to 3 hours.
Forging and cake-making	4 ,,
Total	6 to 7 hours.

Production of Steel by Puddling.

In 1824 Bréant published an interesting paper on cast-steel, in which is the following prophetic passage:[5]—"The darkest pig-irons (*les fontes les plus noires*) succeed best. I am convinced that with such pig-irons, it would be possible to produce cast-steel on a very large scale in reverberatory furnaces, by following a process analogous to that of the depuration of bell-metal, that is to say by adding to the metal in fusion a portion of the same metal oxidized; or, still better, natural oxide of iron." After the lapse of several years, this prophecy was fulfilled; and puddled steel is now an article of great commercial importance.

According to Tunner, puddled steel was actually made at Frantschach, in Carinthia, so long ago as 1835, by Schlegel, Müller, and Mayr, who obtained a patent for the process in the following year; but the process was soon put aside.[6] In 1846, M. Bischof made puddled steel in a gas-furnace at Mägdesprung, in the Harz. At Weyerhammer in Bavaria, and at Limburg in Westphalia, it has been tried during several years.[7] In 1849 some ironmasters in Westphalia made consecutive trials of it on a large scale, and succeeded in overcoming every difficulty. In 1850 puddled steel, suitable for several purposes, was regularly fabricated. In the International Exhibition of 1851, Messrs. Lehrkind, Falken-

[5] Annales des Mines, 1824, 9. p. 327. The title is "Description d'un procédé à l'aide duquel on obtient une espèce d'acier fondu semblable à celui des lames damassées de l'Orient. Par M. Bréant, vérificateur des essais à la Monnaie."

[6] Jahrbuch, Tunner, 1853. 3. p. 281.

[7] De la Fabrication de l'Acier Puddlé en Allemagne. Par M. A. Delvaux de Fenffe, Ingénieur Civil des Mines, Professeur aggrégé chargé du cours de Metallurgie à l'Université de Liége. Revue Universelle, 1857. 1. p. 59.

roth, & Co., of Haspe, near Hagen, in the Principality of Lippe, showed bars and blooms of puddled steel made from German charcoal pig-iron, from Belgian refined metal, and from Yniscedwyn pig-iron.[a] It was stated to be employed in large quantities on the Continent for the manufacture of cutlery, waggon axle-trees, files, springs, etc.; and was exhibited for its cheapness, hardness, tenacity, and elasticity.[b] The first steel puddling furnace at the Works of the firm above-mentioned came into operation in September, 1850. In the Report of the Jury of Class I., drawn up by Dufrenoy, only the following curt notice appears: "The steels exhibited by Messrs. Lehrkind, Falkenroth, & Co., of Haspe, have been obtained by a peculiar method in the puddling furnace. According to Mr. Schreiber, their price is lower than that of other German steels, being sold at 22*l.* per ton. It would seem that similar attempts have been made in other works, but without success." Rolled puddled steel was also exhibited by Boeing, Boehr, and Lefsky, at Limburg, on the Lenne;[1] and by Huth & Co., Hagen.[2] This important manufacture was, at the time, perfectly novel.[3] In the International Exhibition of 1862, illustrations of puddled steel abounded. The puddled steel of Messrs. Lehrkind & Co. was, I presume, made by what is known as Riepe's process; for, in the *Official Catalogue*, Mr. E. Riepe is announced as their agent in London, and the process has been patented in England in the name of Ewald Riepe; but I do not know whether he is entitled to the credit of the invention.[5] According to M. Lan, the puddling of steel deserves only to be classed amongst metallurgical processes from the date when it was practised by MM. Morel, Petin, et Gaudet, in the Loire, about 1845 or 1846; and he further announces that afterwards only a single step remained to be taken, and that step was taken about 1851 or 1852 in the steel-works of Westphalia.[6] In the same paper (p. 105), Lan

[a] Official Catalogue. Zollverein States. No. 447.

[b] Illustrated Catalogue. Foreign States. p. 1074.

[1] Jahrbuch, Tunner, 1852. 2. p. 180.

[2] Official Catalogue. No. 453.

[3] Ibid. No. 632.

[4] The exhibition of puddled steel, as an article of regular manufacture, was assuredly novel to the world in general, notwithstanding such steel may have been long previously made in Styria. Director Tunner, in his Report on the International Exhibition of 1851, does not acknowledge that the firm at Haspe is entitled to any credit for the introduction of puddled steel. He says, "So far from there being any novelty, the thing was done practically by Schlegel, Muller, and Mayr in Styria, sixteen, actually eighteen years previously; but was soon thrown aside. The puddling of steel was also attempted years ago at Weyerhammer in Bavaria, at Limburg on the Lenne in Westphalia (likewise represented in the Exhibition), and several other countries and places, generally in consequence of the accidental production in the puddling of iron of badly puddled steel-like balls; but it was everywhere given up, or only slightly practised. I found nothing actually new of importance at Haspe; only the workmen there knew very exactly the right moment when to stop the puddling, and had some knacks (*Arbeitsvortheile*, which would be best translated by the vulgar word 'dodges'), which perhaps in other localities had not been so far perfected."—Op. cit. p. 181. It is clear that at Haspe puddled steel was made in a satisfactory manner; and it is also clear that in Styria, supposing likewise the process to have been carried out successfully, its value was not recognised as it ought to have been. Any way, then, the Haspe firm is entitled to great credit.

[5] Improvements in the Manufacture of Steel. A.D. 1850, Jan. 29. No. 12,950.

[6] Annales des Mines, 5. s. 1859. 15. p. 104.

admits that "the first trials in the manufacture of puddled steel were made by German workmen, towards the end of 1854 or at the beginning of 1855, in the basin of the Loire"! Gruner asserts that, "as to steel properly so called, the problem, in an industrial point of view, was only really solved by the combined efforts of several managers of Westphalian forges."[7] How far Lan is justified in claiming this credit for his countrymen, the reader is now in a condition to judge for himself.

Riepe's process was first practised in England at the Mersey Steel and Iron Works, Liverpool; and a valuable paper on the subject was communicated, Jan. 20, 1858, to the Society of Arts by Mr. William Clay, the manager. According to Mr. Clay, a licence was granted, about the date of the patent, to the Lowmoor Iron Company, who, when his paper was read, had made about 1000 tons of puddled steel, which they sold direct to various Sheffield houses, more especially that of Naylor, Vickers, & Co., who "have used this material very largely for the manufacture of their cast-steel bells." Mr. Vickers, who was present at the reading of Mr. Clay's paper, observed that "the puddled steel manufactured by the Lowmoor Company had not come much into use, owing to the high price they had put upon it."

Riepe's process.—In the specification of the patent the process is described as follows :—"Firstly. I employ the puddling furnace in the same way as for making wrought-iron. I introduce a charge of about 280 lbs. of pig-iron, and raise the temperature to redness. As soon as the metal begins to fuse and trickle down in a fluid state, the damper is to be partially closed, in order to temper the heat. From 12 to 16 shovelfuls of iron cinder discharged from the rolls or squeezing machine are added, and the whole is to be uniformly melted down. The mass is then to be puddled with the addition of a little black oxide of manganese, common salt, and dry clay, previously ground together. After this mixture has acted for some minutes, the damper is to be fully opened, when about 40 lbs. of pig-iron are to be put into the furnace, near the fire bridge, upon elevated beds of cinder prepared for that purpose. When this pig-iron begins to trickle down, and the mass on the bottom of the furnace begins to boil and throw out from the surface the well-known blue jets of flame, the said pig-iron is raked into the boiling mass, and the whole is then well mixed together. The mass soon begins to swell up, and the small grains begin to form in it and break through the melted cinder on the surface. As soon as these grains appear, the damper is to be three-quarters shut, and the process closely inspected, while the mass is being puddled to and fro beneath the covering layer of cinder. During the whole of this process the heat should not be raised above cherry redness (?), or the welding heat of shear steel. The blue jets of flame gradually disappear, while the formation of grains continues, which grains very soon begin to fuse together, so that the mass becomes waxy, and has the above-mentioned cherry redness. If these precautions are not observed,

[7] Annales des Mines, 1859. 5. s. 15. p. 236.

the mass would pass more or less into iron, and no uniform steel product would be obtained. As soon as the mass is finished so far, the fire is stirred to keep the necessary heat for the succeeding operation, the damper is to be entirely shut, and part of the mass is collected into a ball, the remainder always being kept covered with cinder slack. This ball is brought under the hammer, and then worked into bars. The same process is continued until the whole is worked into bars. When I use pig-iron made from sparry iron ore or mixtures of it with other pig-iron, I add only about 20 lbs. of the former pig-iron at the later period of the process, instead of about 40 lbs. When I employ Welsh or pig-iron of that description, I throw 10 lbs. of best plastic clay, in a dry granulated state, before the beginning of the process, on the bottom of the furnace. I add, at the later period of the process, about 40 lbs. of pig-iron as before described, but strew over it clay in the same proportion as just mentioned. I do not claim the commencement of the above described process for making steel in the puddling furnace, but what I claim is the regulating the heat in the finishing process, and excluding the atmospheric air from the mass in the manner as described, and also the use in addition of iron to the mass towards the later part of the process."

Mr. Clay stated that although he had only the specification as his guide, having never before heard of or seen the operation, yet he succeeded perfectly in the first trial which he made, and produced such excellent steel, that after working about 100 tons of it, he hardly made better afterwards. He used pig-iron of all descriptions, North Welsh, South Welsh, Staffordshire, and Scotch, with the same result, and without finding the difference, which he expected, between hot and cold blast pig-iron. The steel which he obtained by this process had all the characteristic properties of steel; and he expressed his belief that it would be "useful in the arts for all purposes for which steel is required, except, perhaps, for the finer descriptions of tools and cutlery." Mr. Clay found that while the tensile strength of a puddled steel-bar was about 43 tons to the square inch, that of a puddled iron-bar was only about 20 tons.

Good puddled steel may be, and is perfectly well, made in an ordinary puddling furnace from pig-iron of suitable quality, and the cinder usually employed in puddling iron. The art essentially consists in a nice regulation of the temperature, which should be lower than in puddling iron, and in arresting the process at the proper stage of decarburization. Mr. Parry, of the Ebbw Vale Iron-works, where considerable experience in this art has been acquired, and where I have seen it practised, has published a short, yet very sensible paper on the subject, from which I extract the following details.*

The usual charge is from 4 cwts. to 4¼ cwts. of good bright grey, or low dark grey pig-iron, which is melted at a pretty strong heat; after which the temperature must be reduced, so as to retain the molten metal of the consistency of thin cream. While in this state, it should be

* Proceedings of the South Wales Institute of Engineers, 1863. 3. p. 75.

diligently stirred with a rabble, and well mixed with the cinder previously introduced, and which need not exceed the quantity commonly used in puddling iron. Boiling takes place, owing to the escape of carbonic oxide, produced by the combustion of the carbon of the molten metal at the expense of the oxygen of the oxide of iron in the cinder. If the heat be too high, and the metal, in consequence, extremely liquid, the mixed cinder and metal immediately separate from each other after the operation of rabbling, and decarburization then proceeds slowly, compared with what occurs when the cinder and metal are rabbled in a plastic or less liquid state. If, on the other hand, the temperature be too low, and the metal, in consequence, too stiff, the cinder cannot be equably intermixed, and the steel will not be homogeneous. In a short time the effervescence, from being sluggish, becomes very vigorous; and if a portion of the metal be withdrawn from the furnace at this stage, its fracture, when cold, will be silvery white, the whole of the carbon being in the combined state. The temperature of the furnace may now be raised, but not so high as in puddling iron, and continued until incipient solidification occurs, which will be indicated, as usual, by the appearance of floating granules; it must then be reduced to about a full yellow heat, and the process of balling and finishing the charge may be proceeded with in the ordinary manner. If the temperature, during this last stage, be kept too high, either iron, or steel containing too little carbon, will be obtained. Considerable skill, which can only be attained by experience, is essential for the proper management of this delicate part of the process. When a hard, or more strongly carburized variety of steel is required, a comparatively low temperature is necessary; but it then becomes difficult to effect a complete welding together of the granules which form the ball, especially when pig-iron, containing much silicon, is operated on. In this case, according to Mr. Parry, the cinder produced is not rich enough in oxide of iron to form a good "welding cinder" at the period of balling up, and defects, consequently, become manifest in the puddled bar. Mr. Parry is of opinion that borax might be beneficial, but its price precludes its use. He further suggests that the steel might be transferred from the furnace, in which it is made, to another adjacent furnace, containing a bath of rich cinder, and there formed into balls. As the bath of cinder became weakened, it might be renovated from time to time, by the addition of scrap or scale; and one such furnace would serve for several puddling furnaces.

There is now no fear of a patent which was granted in 1852 for the simple method which has just been described.[9] A charge of about 4 cwts. of grey pig-iron is "melted in the puddling furnace in the ordinary way, with a large quantity of silicate of iron or other metallic oxide," etc. The last clause is not consistently expressed. If silicate of iron be used, the words "or other metallic *oxide*" should not have been employed. Admitting this patent to be valid, it might without

[9] A communication in the name of William Whittaker Collins. A.D. 1852, March 24. No. 14,033. Abridgments, p. 116.

much difficulty be made to include the ordinary method of puddling. Whatever opinion may be entertained as to the expediency of patents, there can be no doubt that such a patent as this ought never to have been granted. A patent, even though it may be proved invalid, confers upon its possessor a *locus standi* in the eye of the law, and enables him thereby to involve innocent persons in most expensive litigation, to say nothing of the attendant annoyance and anxiety. The preliminary examination before the Attorney or Solicitor-General is in many cases an absolute farce, and nothing less. The present system, although confessedly an improvement on the old one, is yet in many cases highly obstructive and injurious to national interests.

Spiegeleisen has been found admirably suited for the production of puddled steel of the best quality, and accordingly it is largely consumed for the purpose. This variety of pig-iron, it will be remembered, is made from highly manganesiferous ores, such as spathic carbonate; it contains generally about 5% of carbon in the combined state, and seldom less than about 4% of manganese. One advantage ascribed to the action of manganese is that it renders the cinder more fusible, so that in the balling process the cinder remains longer liquid, and can therefore be more completely extruded than in the case of a cinder which, being less fusible, sooner thickens and solidifies.

Mr. Parry simply and intelligibly explains why the temperature should be lower in puddling steel than in puddling iron. The "boiling" molten metal remains liquid for a longer time when the temperature of the furnace is high than when it is low; and consequently, before solidification, it must be more decarburized in the former case than in the latter, and be converted into iron or steel accordingly. It is asserted by Mr. Parry that it is next to impossible to produce puddled steel from refined metal; and the reason which he alleges is that in the operation of refining the pig-iron generally loses from ½% to 1% of carbon, and will therefore require for its fusion a higher temperature in the puddling furnace. Moreover, only little rabbling is required to solidify the molten metal; and as the temperature from the period of fusion is necessarily high, the solidified metal cannot retain sufficient carbon to constitute steel by the time the operation of balling is completed. Common white Welsh pig-iron, on account of the large proportion of sulphur which it usually contains, cannot be employed for puddled steel. Mr. Parry is of opinion that the only defect of puddled steel is its indisposition to weld perfectly; and this is a matter of great importance in articles manufactured from it, which are exposed to much wear and tear. This defect is, however, entirely obviated by the subsequent fusion of the steel, which is now practised on a very large scale, especially by Krupp of Essen. Want of homogeneity, due in great measure to the intermixture of cinder—which, as has been already remarked, can never be completely expelled by any amount of pressure from such a mass as a ball, whether of iron or steel—will never be remedied except by absolute fusion.

In Mr. Parry's paper the following example is given of the mean composition of puddled steel, and of the pig-iron from which it had

been derived, and which was of the quality generally known as "dark-grey iron:"—

	Puddled steel.	Pig-iron.
Carbon	0·501	2·680
Silicon	0·106	2·212
Sulphur	0·002	0·125
Phosphorus	0·096	0·426
Manganese	0·144	1·230
Iron, by difference	99·151	93·327
	100·000	100·000

The large proportion of silicon in the pig-iron indicates that the carbon must have existed almost wholly as graphite.

COMPOSITION OF CINDER PRODUCED IN PUDDLING STEEL.

It is, as might be expected, very similar to, and may be identical with, that of ordinary tap-cinder. The following analyses are presented in illustration:—

	I.	II.
Silica	26·0	23·5
Protoxide of iron	55·9	66·0
Protoxide of manganese	10·5	8·4
Alumina	6·8	3·3
Lime	0·6	..
	99·8	101·2

I. By Schnabel, from the Lohhütte, near Siegen. Its specific gravity was 3·643. Very good, pure puddled steel was produced, and the working condition of the furnace is stated to have been very "Rohgang."[1]

II. By the same analyst and from the same locality. Its specific gravity was 4·127. The working condition of the furnace is stated to have been somewhat "Gaargang."[2] Both these cinders approximate in composition to the formula $3FeO, SiO^3$. In No. I. the ratio between the oxygen of the silica and that of the bases is 16·69 : 14·95, and in No. II. it is 13·75 : 16·56. The following elaborate formulæ are proposed for them:—

$$5(3FeO, SiO^3) + 3\,\overline{Mn, Ca}\,O, 2SiO^3 \text{ and } 4(3FeO, SiO^3) + 3(2FeO, SiO^3) + 3(6FeO, SiO^3).$$

It will be remembered that we failed utterly in producing a slag more highly basic than tribasic. These formulæ, like many others, are probably more conjectural than real.

According to Lan, the composition of the cinder produced in puddling steel in the Loire differs considerably from that indicated in the foregoing analyses, at least in the instance in which Lan saw the operation performed, and collected specimens at successive stages.[3] The charge consisted of 80 kil. of "grey very graphitic" pig-iron from Allélik,

[1] Kerl, Handbuch, 1861. 1. p. 875.
[2] Ibid.
[3] Annales des Mines, 5. s. 15. p. 104 *et seq.*

Algeria, and 130 kil. of "mottled grey" pig-iron from Sollenzara in Corsica. The pig-irons contained the following ingredients per cent.:

	Algeria.	Sollenzara.	Mean of the charge.
Carbon	3·65	4·30	3·980
Silicon	1·13	2·05	1·658
Manganese	2·11	traces	1·055

The sulphur was not quantitatively determined, but was present only in minute proportion. Neither phosphorus nor copper was detected. The bed of the furnace was "fettled" at a white heat with from 20 kil. to 25 kil. of hammer-slag and roll-scale. The time occupied in the various manipulations is as under:—

	Minutes.
1. Repairing bed, charging, etc.	7
2. Fusion	40 to 45
3. Mixing molten metal and cinder together	25 to 30
4. Rabbling, effervescence	20 to 25
5. Balling up	6 to 8
Time lost between two consecutive charges	5
Total	1^h 43^m to 2^h

When the work is well conducted upon a bed made with the oxide of iron resulting from working off scrap-balls, the loss upon the charge of pig-iron may amount only to 4 % or 5 %, and at the maximum it does not exceed 10 % or 12 %. The consumption of coal varies from 130 to 150 for 100 of steel, and with inferior coal it reaches from 160 to 180.

Analyses of the Cinder.

	I.	II.	III.	IV.
Silica	14·50	17·50	15·00	14·50
Protoxide of iron	83·12	81·14	82·00	83·50
Oxide of manganese / Traces of other bases	2·38	1·36	3·00	2·00
	100·00	100·00	100·00	100·00

I. It was taken out at the end of the second period (see foregoing table of time consumed in the successive manipulations), when the bath was perfectly liquid, and slightly undulated by the disengagement of some gaseous bubbles. II. It was taken out ¼ hour afterwards, thickening not having yet occurred, and the effervescence having much diminished. III. It was taken out 25 or 30 minutes after the last, the effervescence being at its maximum; *the pig-iron* and *the cinder* could no longer be removed separately, and they were subsequently assorted when cold. IV. This was the cinder remaining in the furnace after the completion and removal of the balls. The mean ratio between the oxygen of the silica and that of the bases, is from 1 : 2 to 2·5. These results, Lan observes, show that the cinder changes extremely little in composition, and that it is extraordinarily rich in oxide of iron. It is to be regretted that Lan should not have presented us with analyses somewhat more elaborate; and it would have been satisfactory to have had the assurance that these cinders contained no sesquioxide of iron,

which I suspect they may have done. The use of such rich cinder (*i. e.* rich in oxide of iron) is directly opposed to the statement, for example, of Fenffe, that one of the essential differences between the puddling of steel and iron is the poorer cinder (*scories plus crues*) employed for the former.[4]

ANALYSIS OF PUDDLED STEEL.

Carbon, combined	1·380
Carbon, graphitic	trace
Silicon	0·006
Sulphur	..
Phosphorus	trace
Manganese	0·012

Puddled steel from Königshütte, with "rose" fracture. By W. Brauns.[5]

SPECIAL MODIFICATIONS IN THE PROCESS OF PUDDLING STEEL.

The addition of *nostrums*, of various kinds, during the operation of puddling, has been proposed; and, as might have been anticipated, there is much division of opinion as to their effect. Steel-improving doctors, with pretended mysteries, have sprung up copiously of late.

Schlegel and Müller, in their patent previously referred to, prescribe the following mixture, and how it should be administered:—"The pig-iron should be melted down at a strong heat, and after it has become uniformly liquid, the temperature should be somewhat reduced. The refined pig-iron soon begins to boil, and at this stage the special materials should be added. These consist of a mixture of lamp-black, not too finely pulverized, ox-hoofs hacked in pieces about half a cubic inch in size, and finely ground common salt. For 350 lbs. of pig-iron should be used 5 lbs. of lamp-black, 4 lbs. of hoofs, and 1 lb. of common salt. This mixture is to be divided into about 12 parts and wrapped up in paper parcels, which, during the boiling, are to be successively introduced and immediately stirred well in with the molten metal. At this stage the temperature should be kept moderate, the damper being down as closely as possible in order to lessen the draught."[6]

According to Tunner, in making the commonest puddled steel, clay is often employed, or more frequently instead, quartzose or argillaceous iron ores, which render the cinder less rich; but he recommends as preferable, substances analogous to "Schafhäutl's patent powder,"[7] brown iron-ore and common salt. Tunner supposes that the brown iron-ore, in the first period of the rabbling, evolves free oxygen (from

[4] Op. cit. p. 65.

[5] Wagner, Jahres-Bericht. 1861, p. 75.

[6] Jahrbuch, Tunner, 1853. 3. p. 282.

[7] This powder was patented A.D. 1835, May 13 (No. 6837). It was used in the manufacture of malleable iron. It consisted of an intimate mixture of 1¾ lb. of black oxide of manganese (MnO^2), 3¾ lbs. of well-dried common salt, and 10 ozs. of well-washed potter's clay. This mixture is to be melted with 3¾ cwts. of pig-iron in the boiling process of puddling; and it is recommended to add it in three successive portions.

the oxide of manganese contained in it, which acts energetically like a blast of air in separating foreign matters, and that the residual protoxide of manganese tends to form a thinly liquid cinder, although some of this oxide must be reduced in order to be beneficial in the production of steel. The common salt, Tunner thinks there is no doubt, acts advantageously by disengaging chlorine, which causes "many of the noxious ingredients of the pig-iron" to volatilize: whilst its base, by partially combining with alumina, renders the cinder liquid. Moreover, the soda contributes essentially to the formation of cyanogen, "whereby the formation of steel by means of cementation, especially after the termination of the rabbling period, is greatly promoted."[a]

The mode of action of common salt as explained by Tunner, is not so clear as he seems to suppose. What are the "noxious ingredients" alleged to be volatilized by the free chlorine? Are they sulphur and phosphorus? If so, they must escape in combination with chlorine. But it would be desirable to ascertain by experiment the action of molten pig-iron on the chlorides of these elements. Chloride of sodium is readily decomposed, at a high temperature, by the action of free silica and the vapour of water, with the formation of hydrochloric acid; and it is at least probable that at a high temperature chlorine and silicate of soda would be formed under the combined influence of silica and the free oxygen evolved from the peroxide of manganese; notwithstanding Gruner asserts that "it is easy to prove that oxygen alone is disengaged under these conditions."[b]

Gruner has endeavoured to ascertain what becomes of the soda in this process, from the analysis of the cinder of a steel puddling furnace in which common salt had been used. The cinder flowed like water, but solidified pretty quickly. It had the following composition:

		Oxygen.
Silica	17·8	9·25
Protoxide of iron	69·1	19·16
Protoxide of manganese	9·4	
Lime	0·4	
Magnesia	0·4	
Soda	0·9	
Alumina	1·8	
	99·8	

The soda was sought for with care, and determined successively as carbonate and sulphate. Gruner does not state whether he sought for the presence of chlorine in the cinder, and this is obviously a point which should also have been carefully ascertained. The cinder contained scarcely sensible traces of sulphur. Soda, in the proportion of 1 %, should increase the liquidity of the cinder, and tend to abstract the silicon, phosphorus, and even sulphur from the pig-iron. But these are points which must be settled by experiment, and not left to conjecture. And the same may be remarked of Tunner's supposition,—for it is nothing more,—that chloride of sodium may be useful in

[a] Jahrbuch, 1853. 3. p. 291.

[b] Annales des Mines, 1859. 15. p. 315.

furnishing soda, and so in promoting the formation of cyanogen in the manner previously described. Tunner, however, is of opinion that soda in this respect plays a part of the highest importance, if it be desired to produce the hardest puddled steel; and he maintains that potash would act still more energetically in the same way, an opinion founded on experiments on the large scale upon the production of steel by cementation. That cyanogen, or some compound of this radical, may be really potent agents in certain operations relating to steel, can no longer, I think, be doubted; but whether common salt in the puddling of steel acts as Tunner supposes, can only be decided by accurate experimental investigation, which demands the greatest analytical skill. It is well observed by Tunner, that most of the mysteries of steel-puddlers consist essentially in the use either of cyanogen compounds, or of nitrogenous matters capable of yielding cyanogen at high temperatures.

In illustration of the last statement, the following patented processes may be adduced.

Kimball's patent.[1]—Iron is to be converted into steel by cementation with a mixture prepared by heating to redness—sal-ammoniac 1 oz., borax 1 oz., alum 1 oz., fine salt 1 quart. The mixture, on ceasing to smoke, is allowed to cool, and then pulverized. The powder is boiled with a liquid composed of 1 quart of vinegar and 2 quarts of urine, mixed with strong soot 4 quarts, pulverized burnt leather 2 quarts, burnt horse-hoof 2 gills, and fine salt 1 pint, and the whole is afterwards evaporated to dryness. The residue is to be sifted fine, and mixed with the other compound first prepared. The quantities above stated are sufficient for about 1 cwt. of iron.

Holland's patent.—Silk waste of every kind, including that left on the cocoons of silkworms, with the contained chrysalises after winding off the silk, is to be torrefied or highly dried without being carbonized, and then ground to fine powder. Iron bars may be converted into steel by cementation in this powder; or even iron-ores may be so converted by melting them, properly prepared with layers of this powder, in crucibles.[2]

Boullet's patent.[3]—Iron is cemented with a substance consisting of sugar, horn-dust or shavings, animal fat or blood, and wood-charcoal dried and pulverized.

Patent in the name of Brooman.[4]—Iron is melted in pots with compounds of cyanogen and sal-ammoniac. A mixture, consisting of 10 ozs. of charcoal, 6 ozs. of common salt, ½ oz. of brick-dust or oxide of manganese, 1 oz. of sal-ammoniac, and ½ oz. of ferrocyanide of potassium, is melted in crucibles with 50 lbs. of iron.

Thomas's patent.[5]—A mixture, consisting of 16 parts by weight of

[1] For converting Iron into Steel. Nathaniel Kimball. A.D. 1825, Oct. 13. No. 5263. Abridgments, p. 31.

[2] John Holland, A.D. 1849, July 18. No. 12,705.

[3] Jean F. J. A. Boullet, A.D. 1854, Oct. 11. No. 2174.

[4] A communication, A.D. 1856, Feb. 12. No. 359. Abridgments, p. 218.

[5] A communication, George Cumming Thomas, A.D. 1856, Sept. 3. No. 2039.

common salt, 3 of ferrocyanide of potassium, 1 of bichromate of potash, and 4 of pulverized animal charcoal, is used as a cementing powder or added to *molten* iron (!), in the proportion of 1 to 40 of iron.

Binks's patent.[6]—Cyanogen or ammoniacal compounds, or a mixture of their elementary constituents, are claimed.

Binks's second patent.[7]—Cyanogen compounds are again claimed by this patentee. Currents of nitrogen, carbonic oxide, and ammonia, or ammonia alone, are to be passed through decarburized molten iron.

It is needless to remark that if anything like discrimination had been exercised by the law officers of the Crown with reference to several of these patents, they would never have been granted.

With regard to the addition of clay, Gruner, probably with reason, declares it to be worse than useless; and he further states that it has now nearly everywhere been abandoned.

Of all the patents granted with reference to the manufacture of iron or steel, one of the most extraordinary is that of Mr. Charles Low.[8] Cast-steel is to be made by fusing malleable iron in crucibles with a mixture of about 42 parts by weight of black oxide of manganese, 8 of plumbago, 14 of charcoal, and 2 of nitre! The operation would probably be interesting as a pyrotechnic display.

UCHATIUS'S PROCESS.

This process, which was patented in 1855, consists essentially in effecting partial decarburization of pig-iron by fusion in contact with oxide of iron, or other substances capable of yielding oxygen.[9] The pig-iron is granulated by running the molten metal into cold water. The granulated metal, being mixed with about 20 % of roasted pulverized spathic iron-ore and 4 % of fire-clay, is fused in clay crucibles in an ordinary cast-steel furnace. The finer the pig-iron is granulated, the softer, or what is equivalent, the more decarburized, will be the steel, *i. e.* with a given proportion of oxide of iron. The softer sorts of welding cast-steel may be obtained by an addition of good wrought-iron in small pieces, and the harder sorts by adding charcoal to the mixture above described.

The theory of the process is so obvious as scarcely to need a word of explanation. The carbon in the pig-iron is partially burned at the expense of the oxygen of the intermixed iron-ore, and escapes as carbonic oxide, an equivalent proportion of iron being reduced. The quantities of pig-iron and ore must be accurately adjusted in order that the resulting metal may retain the proper amount of carbon to constitute steel. In the partial decarburization of the pig-iron, there is loss in weight, but this is far more than compensated for by the reduction of the oxide of iron to the metallic state. The weight of the cast-steel produced should, it is stated, exceed that of the pig-iron

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[6] Christopher Binks, A.D. 1856, Nov. 14. No. 2695.

[7] A.D. 1856, Nov. 15. No. 2711.

[8] A.D. 1844, May 25. No. 10,204. Abridgments, p. 70.

[9] Franz Uchatius. An improvement in the process of Manufacturing Cast Steel. A.D. 1855, Oct. 1. No. 2189. Abridgments, p. 203.

employed by about 6 %. It will be observed that spathic iron-ore is recommended, on account of the manganese which it contains. The clay acts merely as a convenient flux.

The process has been tried in this country, and the objection particularly urged against it is the uncertainty in the quality of the cast-steel. But in Sweden, I am informed on good authority, it is practised with success by C. R. Ulff, Hedemora, Wikmanshyttan, Dalecarlia, specimens of whose Uchatius steel were shown in the Swedish department of the International Exhibition of 1862.[1] This steel is reported to be excellent for sword-blades. In 1862 its selling price was from 50*l.* to 60*l.* per ton. It was made by melting pig-iron with Bispberg magnetic iron-ore and charcoal in clay crucibles of Belgian manufacture, the ore, it is stated, being remarkable for its purity.

The alleged want of uniformity in the cast-steel produced by this process, must, I presume, mainly depend on the want of uniformity in the size of the particles of the granulated pig-iron; and if so, this might be met by the centrifugal method of granulating metals, of which the Baron de Rostaing showed numerous interesting illustrations in the French department of the International Exhibition in 1862. Granulated pig-iron was presented, of which the particles were of various, but perfectly uniform, dimensions in each sample. There is nothing new in the granulation of pig-iron, even with the aid of centrifugal force. Thus, in a patent granted to John Wood in 1761,[2] one claim is for melting down pig-iron in an air-furnace, and reducing it "into small grains (according to art) by pouring it into water upon a wheel or roller turned briskly round." But not only this, for Wood actually practised the decarburizing process of Uchatius, as will appear from the following extract from the specification. The granulated metal is "mixed with various fluxes, according to its nature and the uses for which the iron is intended, as with iron slag or cinder, *scaled* [sic] *or scoria of iron* [the italics are mine], fusible sand and lime, kelp, soaper's waste." These fluxes or additions were "put with the granulated metal into close vessels," etc. The use of cast-iron in thin plates broken into small pieces was also claimed. In a subsequent patent to John and Charles Wood,[3] the use of pig-iron pounded with heavy stampers was claimed, and in other respects the specification is similar to the former. If the pig-iron were not sufficiently "flourished" or "reduced" by one operation, the metal was to be again pounded and treated with the fluxes prescribed.

According to Mushet the process of granulating pig-iron was carried on to some extent at Cyfartha many years ago.[4] The granulated or shotted metal was called "grundy," from the noise produced by the revolution of a large horizontal stone, placed in the water pit, on

[1] No. 65, Official Catalogue.

[2] A way of making malleable iron from pig or sow metal, commonly called cast-iron, by a method entirely new. A.D. 1761, Feb. 5. No. 759. Abridgments, p. 6.

[3] Making cast-iron malleable, without charcoal or blast, in an air-furnace. A.D. 1763, July 29. No. 794. Abridgments, 1. 7.

[4] Papers on Iron and Steel, 1840, p. 12. Mushet says "fifty years ago."

which the iron fell in its descent, and by the motion of which it was thrown to its extremities, thus insuring greater regularity and a more uniform size in the form and bulk of the granules. . . . . . The shotted iron was introduced into large clay pots, along with certain proportions of bloomery cinders, containing from 55 % to 60 % of the peroxide [illegible] of iron. The pots were furnished with lids, and exposed in an air furnace, heated with the flame of pit coal, to a long attenuated heat. . . . . After a few hours' exposure, the cast-iron being thus deprived of its carbon or fusible principle, was rendered capable of standing a higher temperature, of welding together, and of cohering under the repeated blows and pressure of a heavy hammer.

In M. de Rostaing's method of granulation, the apparatus employed consists of a disc of cast-iron, which revolves horizontally at a great velocity, 2000 revolutions in a minute. The disc is cast with a rim, and is filled in with casting sand or other refractory matter. Pig-iron is allowed to run in a small stream into a funnel immediately over the centre of the disc, and, by centrifugal action, it is projected in globules, which fall at distances corresponding to their dimensions. The shotted metal is assorted by sifting.[5] As much as 80 kils. of pig-iron are thrown off in less than 2 or 3 minutes. The operation takes place in a circular chamber, at the bottom of which is a cistern of water. Impalpable dust or smoke of iron is produced, which is carried into a chamber above by currents of air, and there deposited. I have not been able to obtain satisfactory information as to the cost of this process—not even from the inventor himself, with whom I had an interview on the subject. I was, however, much impressed with the beautiful illustrations which he exhibited.

Partial Decarburization of Pig-Iron by Cementation.

We have considered the process of rendering cast-iron to a certain extent malleable by cementing it in hæmatite, and the chemical changes which are thereby induced. So long ago as 1722, Reaumur published the fact that the heating of cast-iron castings imbedded in red oxide of iron (*Safran de Mars*, produced by long continued exposure of cast-iron plates to a high temperature with access of air) softened the metal perfectly, and much more rapidly than all the other matters [such as chalk, calcined bones, etc.] which he had tried.[6] This is the process of which the invention is ascribed to Lucas!

A patent for this process was granted to Samuel Lucas in 1804.[7] Articles of cast-iron are cemented during 5 or 6 days and nights in a steel-converting, or other suitable furnace, with "ironstone, ore, or

[5] Vid. Rapport fait par M. Gaultier de Claubry au nom du Comité des Arts Chimiques (Soc. d'Encouragement pour l'Industrie Nationale), sur le procédé de division des corps à l'état de fusion, présenté par M. le baron de Rostaing. Vid. also an article on the process in the Presse Scientifique des Deux Mondes. Revue Universelle des Sciences et de l'Industrie. Paris, 1862. No. 6, 1. p. 343.

[6] L'Art de convertir le Fer Forgé en Acier, et l'Art d'adoucir le Fer fondu. 1722, p. 472.

[7] Separating impurities from cast-iron without fusing it, and rendering the same malleable, and "improving articles made of cast-iron." A.D. 1804, May 20. No. 2767. Abridgments, p. 18.

some of the metallic oxides, lime, or any combination of these." Cylindrical cast-iron pots are commonly used for the purpose. It is stated that on account of difficulties, at the time believed to be insuperable, no use was made of the patent for a considerable time after it was granted, until Mr. Thomas Lucas of Chesterfield, with the consent of the patentee, his brother, took up the process and succeeded by its means in producing cast cutlery, which, according to Parkes, would take as fine a polish and as fine an edge as articles of best cast-steel.[8]

It is asserted on the authority of another writer that Lucas's invention "was presently turned to a large practical account; and 'the variety of new and useful purposes' to which it might be applied were soon found to include the casting of all sorts of cutlery articles and edge-tools, from the largest to the smallest, with the utmost facility. From that time to the present moment (1831) immense quantities of wares, bearing in the trade the equivocal designation of *run steel*, have been daily cast, and treated on the principle of the forementioned discovery; without, however, the pig metal undergoing any alterative process whatever between the blast-furnace and the melting-pot. The metal commonly used for the purpose is the sort drawn from the rich Cumberland ores."[9] The cast articles were placed upright in small cast-iron tubs, which were filled up either with ground red hæmatite, or more generally smith's scales (*smithy slack*). Such was the malleability thus communicated to the cast-iron, that the author had seen it drawn out by hammering to the fineness of a knitting-needle. The process is still largely employed in Birmingham for bridle bits, stirrups, etc.; and the usual selling price is about 3*d.* or 4*d.* per lb. Of late Messrs. Brown and Lenox have patented the application of this metal, "malleable cast-iron," for the manufacture of pulley blocks, which have been introduced into the navy. A few months ago I saw excellent specimens of them at Woolwich Dockyard; but I was informed that the selling price was 1*s.* 2*d.* per lb., or at the rate of 130*l.* per ton, the original cast-iron costing only 8*l.* or 9*l.* per ton.

In 1759 Lewis published the fact that "Pure cast-iron, surrounded with animal ashes, and exposed to a fire not sufficient to melt it, becomes in a shorter or longer time, according to the strength of the fire and the thickness of the metal, so soft, that ornaments or utensils made of it, however hard before, may now be easily cut, filed, embellished, or freed from their superfluities. The gradual changes, produced in this process, are pretty remarkable."[1]

PRODUCTION OF STEEL BY FUSION OF PIG-IRON WITH MALLEABLE IRON.

It is obvious that steel must be produced by melting malleable iron and cast-iron together in suitable proportions. Early in the last

[8] Essay on Edge Tools. Parkes's Chemical Essays. 1815. 4. p. 519.

[9] Manufactures in Metal. Lardner's Cabinet Cyclopedia. 1831. 1. p. 268.

[1] The Chemical Works of Caspar Neumann, M.D., Professor of Chemistry at Berlin, F.R.S., etc. Abridged and methodized, etc., by William Lewis, M.B., F.R.S. 1759. p. 77.

[illegible] Réaumur published the fact that he had been very successful in making steel in this manner in a common forge. He writes, "I have mixed sometimes a quarter, and sometimes a third of iron with pig-iron."[2]

In 1855 a patent was granted to David Simpson Price and Edward Chambers Nicholson for "Improvements in the Manufacture of Cast-Steel,"[3] by which it is alleged a superior quality of cast-steel may be produced from iron smelted either by coal, anthracite, or coke at a less cost than hitherto obtained. The invention consists simply in melting refined pig-iron with suitable proportions of any kind of malleable or wrought-iron. The refined metal preferred by the patentees is that made by smelting with coal blackband, hematite or spathic ores, and refined so as to have lost the whole or nearly the whole of its silicon, and as little of its carbon as possible. This refined metal is stated to be more free from impurities, especially silicon, than either charcoal or coke pig-iron, whilst the proportion of carbon in it is about the same as existed in the pig-iron from which it was made; and hence it is regarded as a material well adapted for the manufacture of cast-steel. The patentees do not confine themselves to any particular proportions in the admixture of wrought-iron and refined metal, or to any particular mode of effecting the mixture.

Shortly after the date of this patent Mr. Gentle Brown obtained a patent for the manufacture of cast-steel by fusing bar-iron, cut or clipped into small pieces, with good charcoal pig-iron, in the proportion of about 3 parts of the former to 1 of the latter.[4] But these proportions are varied somewhat according to the quality of steel desired.

In 1862 a patent was granted to Charles Attwood,[5] of Tow Law Iron-works, Durham, for "Improvements in the Production or Manufacture of Steel and Iron of a Steely Quality." The essence of this patent consists in melting together malleable iron and cast-iron, by whatsoever manner produced. Spiegeleisen is preferred as "the kind best fitted" for the purpose, "where excellence and uniformity of quality in the steel or steely iron intended to be produced is especially desirable." It is certain that steel well adapted for many objects may be thus made; but spiegeleisen is only a particular variety of cast-iron, and is necessarily included under that generic term; and cast-iron had been long previously employed for exactly the same purpose. The varieties of cast-iron in the form of pig-iron in commerce are exceedingly numerous; and a patentee should hardly be permitted to monopolize a few of these varieties for the object in question, after the application of cast-iron for the same object has been well known and practised. But spiegeleisen, I am informed, has been for some time pretty extensively used in Germany for the production of steel in the manner specified by Mr. Attwood. Moreover, amongst the various claims of Mr. Attwood is "the admixture

[2] L'Art de convertir le Fer Forgé en Acier. 1722. p. 256.

[3] A.D. 1855, Nov. 20. No. 2610.

[4] A.D. 1856, Jan. 25. No. 205. Abridgments, p. 215.

[5] A.D. 1862. Dated May 15th, and sealed Aug. 15th of the same year. No. 1473.

and fusion together of malleable bar or scrap iron with that description of white cast metal or crude iron commonly called metal or finer's metal, etc." Now, this, it will be remembered, is the essence of Price and Nicholson's patent. Mr. Attwood inserts in his specification a claim to Parry's carburized iron to be hereafter described.

Immersion of Malleable Iron in Molten Cast-iron.

In this place may be briefly described an old method of converting malleable iron into steel by keeping it immersed in molten pig-iron; though, perhaps, it might with more propriety have been treated of under the head of Cementation. It will be remembered that in the Paal process of converting pig-iron into steel, this principle is, in a certain degree, acted upon. In 1540, Vanoccio Biringuccio published the following account of making steel by keeping bar-iron immersed in molten cast-iron,[6] and for the translation of which I have pleasure in acknowledging my obligation to Mr. Panizzi, of the British Museum.

"Now with respect to this matter, it might seem that it should rather be looked for to speak of it after the fusion of iron in the ninth book, where I think to treat of it in particular; yet as this business of making steel appears to me a branch, as it were, of the preceding chapter concerning iron proper, I have not wished to displace it so far, that it should appear hereafter as another matter; therefore I have made up my mind to write of it here, and to tell you that steel is nothing but iron well purified by means of art, and through much liquefaction by fire brought to a more perfect admixture and quality than it had before. By the attraction of some suitable substances in the things which are added to it, its natural aridity is mollified by somewhat of moisture, and it is made whiter and denser, so that it seems to be almost removed from its original nature; and at last when its pores are well dilated and mollified with much fire, and when the heat is driven out of them by the extreme coldness of the water, they contract, and so the iron is converted into a hard substance, which from its hardness becomes brittle. This may be done with every kind of iron ore, and so steel may be made of all kinds of iron. It is true, indeed, that it is made better from one kind than from another, and with one sort of charcoal than another, and it is also made better according to the skill of the masters. The best iron to make it good is, however, that which, being by its nature free from the corruption of any other metal, is more easy to melt, and which is to a certain extent harder than other kinds. With this iron is put some pounded marble or other fusible stones in order to melt them together; by these it is purged, and they have, as it were, the power of taking away its ferruginosity, of constricting its porosity, and of making it dense and free from cleavage. Now, to conclude, when the masters wish to do this work they take of that iron passed through the furnace or otherwise, as much as they wish to convert into steel, and they break it into little

[6] De la Pirotechnia. Stampata in Venetia. 1540. Lib. I. cap. 7. p. 18. Vid. p. 48 of the French Translation. Paris, 1556.

bits, then they prepare before the aperture of the forge a circular receptacle about a foot or more in diameter, made of one-third clay and two-thirds small coal (*carbonigia*) well beaten together with a hammer, well mixed, and moistened with so much water as will make them keep together when squeezed in the hand; and when this receptacle is thus made, in the same way as they make a hearth (*ceneraccio*), but deeper, the aperture is prepared in the midst, which should have a little of the nose turned down, so that the wind may strike in the midst of the receptacle. Then, when all the space is filled with charcoal, they moreover make round about it a circle of stones or soft rock to keep in the broken iron and the additional charcoal which they put upon it, and so they fill it up and make a heap of charcoal over it. Then, when they see that the whole is on fire, and well kindled, especially the receptacle, the masters begin to set the bellows to work and to put on some of that crushed iron mingled with saline marble and with pounded slag, or with other fusible and not earthy stones; and so melting this composition by little and little, they fill up the receptacle as far as they think fit; and having first formed with the hammer three or four lumps of the same iron, each weighing 30 or 40 lbs., they put them hot into that bath of melted iron, which bath is called by the masters of this art the art of iron; and they keep them thus in the midst of this melted matter with a great fire about four or six hours, often turning them about with a rod, as cooks do victuals, and so they keep them there, turning them again and again in order that all that solid iron may receive through its porosity those subtle substances which are found to be within that melted iron, by virtue of which the gross substances which are in the lumps are consumed and dilated, and the lumps become softened, and like a paste; when they are seen thus by the experienced masters, they judge that that subtle virtue of which we have spoken has thoroughly penetrated, and taking out one of the lumps which appears best from their experience in testing, and bringing it under the hammer, they beat it out, and then throwing it suddenly as hot as they can into the water, they temper it, and being tempered, they break it, and look to see if the whole of it has in every particle so changed its nature as to have no small layer of iron within it; and finding that it has arrived at that point of perfection which they desire, they take out the lumps with a large pair of pincers, or by the ends left on them, and cut them into small pieces of seven or eight each, and they return them to the same bath to get hot again, adding to it some more pounded marble, and iron for melting, to refresh the bath and increase it, and also to restore to it what the fire may have consumed, and also that that which is to become steel may, by being immersed in that bath, be the better refined; and so at last, when these are well heated they go and take them out piece by piece with a pair of pincers, and they carry them to the hammer to be beaten out, and they make rods of them as you see. And when this is done, being very hot, and almost of a white colour from the heat, they cast them all at once into a stream of water as cold as possibly can be had, of which a reservoir has been made, in order

that the rods may be suddenly cooled, and by this means get the hardness which the common people call temper. And thus it is changed into a material which hardly resembles that which it was before it was tempered. For then it was only like a lump of lead or wax, and by tempering it is made so very hard as almost to surpass all other hard things, and it is also made very white, much more so than is the nature of its iron, even almost like silver; and that which has its grain white, and most minute and fixed, is of the best sort. Among those kinds which I know of, that of Flanders, and in Italy that of Valcamonica in the territory of Brescia, are very much praised; and out of Christendom that of Damascus, that of Caramenia and Lazzimino (?), as well as that of the Agiambi (?). How these people get it, or whether they make it for themselves, I cannot tell you; only I have been told that they have no other steel than ours, and that they file it and knead it with a certain flour and make pellets thereof, which they give to geese to eat, and afterwards they collect their dung which they reduce by fire and make it into steel; I have not much faith in this, but I think that whatever they do, if it is not by the virtue of the iron itself, it is by virtue of the tempering."

A very similar description of a process of making steel, with additional details and an illustrative woodcut, is given by Agricola; but in some respects it is obscure.[7] It might almost be suspected that one of these authors had copied from the other. Biringuccio refers to Georgius Agricola, the German; but Brunet does not allude to any published work of the latter author so early as that of the former.[8]

In the Philosophical Transactions of 1693 is a paper on Steel by Dr. Martin Lister, in which he cites the foregoing description of Agricola, and adds, on the authority of Kircher, that the same method of making steel was then practised in the Island of Ilva (Elba), "a place famous from all ages, even from the times of the *Romans*, for that metal alone, down to our days."[9]

The author of the Treatise on Iron and Steel in Lardner's 'Cabinet Cyclopedia,' in commenting on Lister's paper, ridicules the notion of making steel by boiling "Iron in its own Sow-metal, or Liquid Iron" (the expression used by Lister, and clearly meaning molten pig-iron). We are informed that "the notorious result of such a course, whether the articles were iron or steel, must be precisely similar to what would take place were a pound of candles to be boiled in tallow. Steel, as is well known, is melted with the greatest facility every day in the converting and refining establishments; and malleable iron, however difficult of fusion *per se*, loses all its obstinacy, and presently runs down in the crucible, by admixture with a small portion of cast metal; it is indeed common enough with a class of casters afterwards mentioned to correct the quality, or supply the deficiency of good pig metal, by melting therewith any proportion of old iron that they may

[7] De Re Metallicâ. Lib. IX. 1561. p. 341.

[8] Manuel du Libraire. 1842. 1. p. 43.

[9] The manner of making Steel, and its Temper; with a Guess at the way the Ancients used to steel their Picks for the cutting or hewing of Porphyry. September, 1693. No. 203. 17. p. 865.

think desirable. The test of the crucible is not always at hand even with the translator of an ancient writer on metallurgy."[1]

I am rather surprised that the author of this excellent treatise should have condemned the process as absurd, and still more so that he should have introduced the candle illustration, which is not in the least apposite. It is perfectly true, as the author states, that wrought-iron may be readily melted with pig-iron, but only at high temperatures. Now, the bath of molten pig-iron alleged to have been used in the ancient steel process consisted probably of highly carburized metal fusible at a comparatively low temperature; and in such a bath bars of wrought iron might certainly be immersed for a considerable period without melting down.

Decarburization by blowing Atmospheric Air through Molten Pig-Iron.

On the 15th September, 1855, a patent was granted to Joseph Gilbert Martien, of Newark, New Jersey, United States of America, then residing in London, for the invention of "Improvements in the Manufacture of Iron and Steel."[2] As this patent has excited considerable attention with reference to what is termed the Bessemer process, I present the specification *in extenso*:

"This Invention has for its object the purifying iron when in the liquid state from a blast-furnace, or from a refinery-furnace, by means of atmospheric air, or of steam, or vapour of water applied below, and so that it may rise up amongst and completely penetrate and search every part of the metal prior to the congelation, or before such liquid metal is allowed to set, or prior to its being run into a reverberatory furnace in order to its being subjected to puddling, by which means the manufacture of wrought-iron by puddling such purified cast-iron, and also the manufacture of steel therefrom in the ordinary manner, are improved.

"In carrying out my Invention, in place of allowing the melted iron from a blast-furnace simply to flow in the ordinary gutter or channel to the bed or moulds, or to refinery or puddling-furnaces, in the ordinary manner, I employ channels or gutters, so arranged that numerous streams of air, or of steam, or vapour of water may be passed through and amongst the melted metal as it flows from a blast-furnace.

"I prefer, in carrying out my Invention, that the ordinary process of refining iron by the use of a refinery furnace should be dispensed with, and that the purifying of the iron should be accomplished by subjecting the melted iron from a blast-furnace before it is allowed to congeal to the action of streams of air or of steam passed up through and amongst the melted metal; at the same time I would state, that

[1] Manufactures in Metal. 1831. 1. p. 225.

[2] A.D. 1855. No. 2082. Sealed March 11th, 1856, and dated September 15th, 1855. The precise dates are important, as will be shown presently. The patent right was purchased by the Ebbw Vale Iron Company.

where it is preferred by others still to resort to the ordinary refinery process by remelting, then my Invention is to be applied to the melted metal as it flows from such furnace to a bed or moulds, in like manner to what I will now describe as applicable to a blast-furnace. The channel or gutter employed may be of any suitable material; but I prefer it to be of cast-iron, the bottom part being made hollow to receive steam or air, or both. This gutter is perforated with numerous holes, which I prefer to be inclined, so that the streams of air or steam may be forced through the melted metal (as it flows along the gutter) in an oblique direction, but, by preference, in the direction in which the metal flows. This, however, is not essential, as the streams of air or steam may be passed directly up through the melted metal, or the holes may be inclined in the opposite direction, so as to oppose the flow of the melted metal. When hot blast or cold blast is used, I prefer to connect the hollow bottom of the gutter with the air pipes used for supplying the blast, and when steam is employed I connect the hollow bottom of the gutter with the boiler used. By these means, the air or steam introduced in the hollow bottom of the gutter below the metal will rise up and be forced through it in numerous streams; or, in place of the gutter being the means of applying streams of air below the fluid iron as it comes from a blast-furnace, the moulds or bed into which the melted iron is received may be arranged with means for introducing air or steam below the melted iron, and to divide such air or steam into numerous streams, so that the iron may be purified thereby after it has come from the blast-furnace and before the congelation of the liquid metal takes place.

"The gutter or channel above mentioned may be covered over for any part of its length, and it may be arranged in a suitable manner to admit of heat being applied to the metal therein; and such is also the case with respect to the moulds or beds, in order that heat may be continued to the fluid metal after it has left the blast-furnace, and whilst the process above described of purifying the metal is going on. The iron thus purified may be allowed to cool in the moulds, or it may be run from the gutter, channel, or receiver into a reverberatory or suitable furnace, to be highly heated therein, and may be puddled in the ordinary manner.

"I would remark that I am aware that it has before been proposed to use streams of steam in puddling and refinery-furnaces in such manner as to come in contact with the surface of the melted metal therein, and it has also been proposed to introduce steam below melted iron when puddling the same. And I mention these cases in order to state that I make no claim thereto; but what I claim is, the purifying iron from a blast-furnace or a refinery-furnace while still in a melted state, as herein described."

It is perfectly clear from the specification that the patentee did not propose to effect by his process the conversion of pig-iron, whether unrefined or refined, either into steel or malleable iron; and it is

equally clear that he simply intended it to be employed as accessory to the ordinary process or processes in common use for effecting the conversion of pig-iron into malleable iron. The expression "purifying iron" is ambiguous, and I do not know whether it was meant to signify merely decarburization, or the elimination of such matters as silicon, sulphur, and phosphorus. The essence of the patent seems to consist in exposing a stream of molten pig-iron *in its course* to the action of jets of atmospheric air, of steam, or of a mixture of both, introduced at the *bottom* or *below* the surface of the liquid metal. This, so far as relates to atmospheric air, had not, I believe, been previously done, at least *designedly* or otherwise than accidentally. The patentee emits not the slightest hint to show that he was aware of the fact, that by blowing atmospheric air through molten pig-iron sufficient heat would be developed to keep it in a state of liquidity even for a very short time. Air and steam are spoken of precisely as though they were similar agents and would produce similar effects; whereas their effects would be radically dissimilar. Air would, by oxidizing both the carbon and the iron of the molten metal, not only maintain, but greatly raise the temperature; but steam would cause an immediate reduction of temperature and tend speedily to solidify the molten metal. As we shall presently see, Martien never either did or contemplated doing what Bessemer has done; and it is idle to pretend the contrary. However, in October or November, 1855, that is two or three months prior to the publication of Bessemer's first patent, in which he first announced that he could perfectly decarburize molten pig-iron by blowing air through it without the further application of external heat, the following remarkable experiment was proposed and conducted by Mr. George Parry, of the Ebbw Vale Iron-works; and if an accident had not unfortunately occurred, Bessemer might have been shorn of his glory.

In the bed of a reverberatory furnace several wrought-iron pipes, about 1 in. in diameter, were laid parallel to each other, and about 3 in. apart, in the direction of the long axis of the furnace. The pipes were all put in connection with the blast apparatus. Their upper surfaces were perforated with holes, about 3 in. apart, of which there were about 80 or 100 altogether; and wires having been first stuck in these holes, the pipes were covered solidly over with fire-clay. When the clay bottom, thus formed, had become dry, all cracks in it were carefully filled up with fire-clay; and when this also had become dry, the wires were pulled out. The furnace was very gradually heated, and then about 1½ ton of pig-iron from No. 1 blast-furnace, at the Victoria Works, was run in, the blast having been *previously* let into the pipes. Vigorous action occurred, when, by some mishap, the molten metal escaped from the furnace into the road. The then managing director of the works was unwilling that the experiment should be repeated, and the furnace was dismantled, happily for Bessemer.

We now arrive at the consideration of the Bessemer process, which has of late created so much stir in the iron-making world. This pro-

cess has been the subject of numerous patents, of which the first is dated October 17th, 1855.[3] The invention consists in "forcing currents of air or of steam, or of air and steam, into and among the particles of molten crude iron, or of remelted pig or refined iron, until the metal so treated is thereby rendered malleable, and has acquired other properties common to cast-steel, and still retaining the fluid state of such metal, and pouring or running the same into suitable moulds." Molten pig-iron is run into crucibles previously heated, and contained within a rectangular furnace, having fire-bars placed vertically at the sides, and not at the bottom. Each crucible has a taphole at the bottom, through which the metal is tapped into moulds in a cave underneath the furnace. Steam or air, either separately or together, and by preference raised to a high temperature, is forced downwards through a pipe which descends to the bottom of each crucible. Steam, it is stated, *cools the metal*, but *air causes a rapid increase in its temperature*, and *it passes from a red to an intense white heat.* When the metal is sufficiently decarburized, it is tapped off. In the increase of temperature here recorded is the germ of the invention to be presently described.

In December of the same year Bessemer obtained another patent for "Improvements in the Manufacture of Iron."[4] In this currents of air or steam are directed to be forced up through molten pig-iron, contained within a suitable vessel, by preference spherical or egg-shaped. This vessel may be made of cast, or better of wrought-iron lined with fire-brick; and may be suspended on axes: it should be closed at the top, with the exception of an opening for the introduction of the molten metal, and for the escape of gases and sparks during the passage of the blast upwards through the metal. The mode of injecting the blast will be presently described. When the process has been carried on far enough, as is indicated by the diminished fluidity of the metal, the vessel is turned on its axis, and the metal poured through a lip into an iron mould, so as to form ingots *suitable for puddling*. However, in the specification of this patent, it is recommended as expedient to carry out "the refinement of pig or crude iron by *a single process*, and cast the same into ingots suitable for rolling at once into bars or rods." The characteristic phenomena of the process, as now perfected, are also accurately described. It is preferred to use steam only in the early stage, if used at all. It will be observed that *steam* is still spoken of as a *possible substitute* for *air* in this process.

The next patent to be considered is dated Feb. 12th, 1856.[5] "Molten crude iron or remelted pig or finery iron [refined iron]" is converted "into steel or into malleable iron *without the use of fuel* for reheating or continuing to heat the crude molten metal, such conversion being effected by forcing into and among the particles of a mass of molten iron currents of air or gaseous matter containing or capable of evolving

[3] Henry Bessemer. "Improvements in the manufacture of cast-steel." No. 2321. Abridgments, p. 204.

[4] A.D. 1855, December 7. No. 2768. Abridgments, p. 210.

[5] "Improvements in the manufacture of malleable or bar iron and steel." No. 356. Abridgments, p. 217.

sufficient oxygen to keep up the combustion of the carbon contained in the iron till the conversion is accomplished." The process is conducted as set forth in the specification of the last patent. The operation is stopped when the metal is decarburized to the required extent. For malleable iron it should be continued 5 or 10 minutes longer than for steel. If it be desired to obtain steel of a very superior quality, the iron produced by this process may be granulated in water, and then converted into steel by a method of cementation which Bessemer previously proposed. It will be observed that in this specification the use of steam is not claimed as a substitute for atmospheric air. This is a matter of importance, as it is certain that steam could not be so employed and produce the same effect as atmospheric air. If the validity of a patent depend upon the possibility of effecting certain results by *every* method described in a specification, then, assuredly, every patent in which Bessemer claims the use of steam for decarburizing molten pig-iron without fuel would be invalid.

A fourth patent granted to Bessemer bears date March 15th, 1856, and is for modified apparatus, the air and *steam*, separately or together, being again claimed;[6] and he obtained a fifth patent for improved apparatus, which bears date May 31st, 1856. Bessemer has year after year gone on patenting modifications of his apparatus, and machinery relating to the manufacture of iron and steel. Other persons also have patented various methods of bringing atmospheric air in contact with molten pig-iron, and of these some might certainly be pronounced mere colourable imitations.

But there is one patent which deserves special consideration, and to which Bessemer is deeply indebted. I allude to that of Mr. Robert Mushet, dated September 22nd, 1856.[7] It consists simply in the addition of molten spiegeleisen to Bessemer's decarburized metal while still in a state of liquidity. In attempting to produce steel by the methods specified by Bessemer, it has hitherto been found very difficult, if not impracticable, at least in this country, to ascertain with certainty when decarburization has proceeded to the right extent, and when therefore the blast should be stopped. Accordingly the plan now adopted is to decarburize perfectly or nearly so, and then add a given proportion of carbon in the state in which it exists in molten spiegeleisen, the precise composition of which should of course be known. By this addition the liquidity of the metal is immediately much increased. Mr. Mushet allowed this patent to become void in the third year. So far, spiegeleisen has given a value to Bessemer's process of making steel, which certainly it did not previously possess. It is somewhat singular that even Bessemer himself does not conduct the manufacture of steel *exclusively* according to any of his own specifications. Mr. Mushet could hardly have been aware of the pecuniary value of his patent, or he would not have so gratuitously surrendered his rights.

[6] Improvements in the manufacture of iron and steel. No. 630. Abridgments, p. 220.

[7] Improvements in the manufacture of iron and steel. No. 2219. Abridgments, p. 239.

In a patent granted to Bessemer in 1861[8] he alludes to Heath's application of metallic manganese in the casting of steel, and claims the use of an alloy of manganese and iron, containing a small proportion of silicon, in the production of steel by his own process. He gives directions for preparing such an alloy by reducing conjointly the oxides of iron and manganese, whether artificial or native, in intimate mixture with carbonaceous matter, and also with silica, if it be not present in these oxides in sufficient quantity. The patentee informs us that he has "found that the metals manganese and silicium may be readily reduced in combination with so small a quantity of iron as to facilitate their application instead of causing an inconvenience by an excess of iron or carbon present, as in the natural [*sic*] alloys of these metals with pig-iron." Now, the discovery of Bessemer concerning the reduction of oxide of manganese and silica by carbon in the presence of iron was perfectly well known long anterior to the date of this patent, if not before he was born; and with respect to the alleged inconvenience arising from the use of the so-called "natural alloys," it is remarkable that the patentee and his licensees always employ one of these "natural alloys" richest in manganese, namely, spiegeleisen. Bessemer does not even mention the name of Mushet, or allude to his proposal to add spiegeleisen, except by way of disparaging its use, on the ground of its "causing an inconvenience by any excess of iron or carbon present." In the summary of claims set forth at the end of the specification, it is singular that no reference is made to the employment of the alloy in question.

At the meeting of the British Association at Cheltenham in 1856, Mr. Bessemer communicated a paper on his process to the Mechanical—not the Chemical—Section, with the title, 'On the Manufacture of Iron and Steel without Fuel.'[9] This paper excited much attention, and was the first really public announcement of the invention; but anything more erroneous than its title cannot well be conceived. The pig-iron to be converted is both smelted with fuel, and again melted with fuel before it is treated by Mr. Bessemer. Towards the end of 1856 I had the pleasure of seeing the process in operation at Baxter House, where Mr. Bessemer then resided, and, I confess, I never witnessed any metallurgical process more startling or impressive. After the blast was turned on, all proceeded quietly for a time, when a volcano-like eruption of flame and sparks suddenly occurred, and bright red-hot scoriæ or cinders were forcibly ejected, which would have inflicted serious injury on any unhappy bystanders whom they might perchance have struck. After a few minutes all was again tranquil, and the molten malleable iron was tapped off. At first I doubted whether the metal, which I saw flowing, was actually malleable iron; and after the analysis in my laboratory of a portion of this identical iron, and the detection in it of somewhat exceeding 1 % of phosphorus, my scep-

[8] Manufacture of malleable iron and steel. A.D. 1861, Feb. 1. No. 275.

[9] Brit. Ass. Rep. 1856. p. 162. The title only is given.

ticism was rather confirmed than otherwise. However, I soon became convinced that Mr. Bessemer was correct in asserting that he had succeeded by his process in producing a temperature higher than ever "before attained in metallurgical operations," sufficient, indeed, to render malleable iron as liquid as water. The mass of metal in this case is not heated, as usual, from without under comparatively unfavourable conditions, but active combustion takes place everywhere in the mass itself under conditions the most favourable possible for the development of high temperatures. Mr. Bessemer was not the discoverer of the fact that iron, when heated to a certain degree, say bright redness, might be raised to a much higher temperature by exposure to a blast of cold air, the additional heat resulting from the rapid oxidation of the metal. We have seen that the nailers in some localities use a blast expressly with this object. Now, if solid iron could be thus heated, the same result might reasonably have been predicated with respect to molten pig-iron; but I am not aware that it ever was, or if it had been, it was never applied.

Mr. Clibborn has recently communicated to the Royal Irish Academy an interesting paper, in which he endeavours to prove that the Japanese forestalled Bessemer 300 years ago.[1] In the English version of Mandelslo's Travels, published in London in 1669, it is stated (p. 160) that "They (*the Japanese*) have, among others, a particular invention for the melting of iron, without the using of fire, casting it into a tun done about on the inside with about half a foot of earth, where they keep it (*melting*[2]) with continual blowing, and take it out by ladles full, to give it what form they please, much better and more artificially than the inhabitants of Liége are able to do." Although the description is very defective, yet, I think, it is sufficient to justify the conclusion that the Japanese method differed at least in two essential respects from that of Bessemer. The first is that the air was not blown up through molten pig-iron; for, if it had been, the eruption, so characteristic of the Bessemer process, would speedily have occurred, and would certainly have attracted the attention of the traveller, who, however, makes not the slightest allusion to it. The second is that, supposing the molten pig-iron to have become decarburized, it could not have been cast into *sound* articles, in the manner described. With regard to the second part of Mr. Clibborn's paper, the author was not aware that the nailer's process of increasing the temperature of bright red-hot iron by exposure to a strong cold blast of air had been previously published; but in p. 14 of this volume I have noticed the fact of such publication and given the references.

It may be interesting to the reader to have Mr. Bessemer's own

[1] May 26th, 1862. On the partial combustion of fluid iron, described by Mandelslo in 1639; and of solid iron, now publicly practised in Dublin by means of a blast of common air. By Edward Clibborn.

[2] The context, according to Mr. Clibborn, shows that this word was understood. I have not consulted the original work.

description of the phenomena accompanying his process: it is as follows:[2]—The converting vessel having been heated and charged with molten pig-iron in the manner to be presently described, and the blast let on, "the process is thus in an instant brought into full activity, and small though powerful jets of air spring upward through the fluid mass. The air expanding in volume, divides itself into globules, or bursts violently upwards, carrying with it some hundred weight of fluid metal, which again falls into the boiling mass below. Every part of the apparatus trembles under the violent agitation thus produced, a roaring flame rushes from the mouth of the vessel, and as the process advances, it changes its violet colour to orange, and finally to a voluminous pure white flame. The sparks, which at first were large, like those of ordinary foundry-iron, change to small hissing points, and these gradually give way to soft floating specks of bluish light, as the state of malleable iron is approached. There is no eruption of cinder as in the early experiments, although it is formed during the process; the improved shape of the converter causes it to be retained, and it not only acts beneficially on the metal [how?], but it helps to confine the heat, which, during the process, has rapidly risen from the comparatively low temperature of melted pig-iron to one vastly greater than the highest known welding heat, by which malleable iron only becomes sufficiently soft to be shaped by the blows of the hammer; but here it becomes perfectly fluid, and even rises so much above the melting point as to admit of its being poured from the converter into a founder's ladle, and from thence transferred to several successive moulds."

Attempts have recently been made to ascertain the course of the changes which occur in the Bessemer process, by the spectrum analysis of the flame; but I do not certainly know whether any practical results of importance have been thereby attained.

The Bessemer iron, which I have seen, is bright, almost silvery white, and highly crystalline on fracture, exactly as might be expected. This point has been previously considered. The ingots also, which I have had the opportunity of inspecting, have been more or less porous, or cellular; and I do not know whether Mr. Bessemer has yet satisfactorily succeeded in casting uniformly sound ingots. He has patented several schemes for the purpose, and in a patent, dated Feb. 1st, 1861, he announces that silicon in minute quantity is an effectual preventive. "Both cast-steel and malleable iron," he states, "when in a molten state, frequently disengage gases so rapidly as to flow or boil over the tops of the moulds in which they are poured, and thus form ingots or castings containing numerous cells. Now, I have found that this tendency of the metal to disengage gases and boil spontaneously is counteracted by the employment of a very small quantity of the metal silicium, one pound in weight of which is sufficient when diffused through two thousand pounds of molten steel [he does

[2] Proceedings of the Institution of Civil Engineers. May 24th, 1859. Vol. 18. No. 1012.

not add iron] to destroy this tendency to ebullition, and cause the metal to lie quietly in the mould." The porosity seems to be due to the retention of carbonic oxide. Whether this gas may be in any degree dissolved in the molten iron, and evolved at the time of solidification, I am not aware.

M. de Cizancourt has recently communicated a paper to the French Academy, in which he propounds some rather singular views with respect to steel. He states that gases always exist in molten steel or more or less carburized iron, and that their amount increases with the temperature. These gases are always evolved in a very sensible manner during cooling previous to solidification. "Sometimes they appear to be partially fixed, when crystallization intervenes, as occurs particularly in hard steels; whereas in mild steels, and that in proportion to their mildness, the gases by their disengagement occasion phenomena quite analogous to 'spitting' [in the cupellation of silver.]" The author maintains that molten steel and more or less carburized iron capable of being drawn out, always contain in solution gases saturated with carbon; and that, on the contrary, the presence of oxidizing gases in these substances suffices to render them incapable of being drawn out. Steels of different hardness always result from the action of "carbonic gas" (carbonic oxide) more or less mixed with nitrogen upon the iron. The elasticity of hardened steel proceeds from that of the imprisoned gas![4] No experimental evidence whatever is offered in support of these views; and in the absence of such evidence, they will not be readily accepted.

The silicon appears to be oxidized before the carbon, along with a portion of the iron, whereby a porous cinder of silicate of protoxide of iron is formed. The oxidation of the carbon then follows, even to complete decarburization. By operating on a pure variety of pig-iron, malleable iron of remarkable purity may be obtained by the Bessemer process, as will be seen from the following analysis by Mr. Abel, of the Royal Arsenal, Woolwich, of a specimen of Bessemer iron:[5]—

	Per cent.
Carbon, graphitic	0·00
Carbon, combined	minute quantity.
Silicon	0·00
Sulphur	0·02
Phosphorus	trace.
Manganese	trace.

With regard to sulphur and phosphorus, these elements are, unfortunately, not eliminated in a sensible degree, as is admitted by Mr. Bessemer himself in the paper cited. I have already advanced evidence of the fact as to phosphorus; and pointed out a remarkable difference in that respect between the ordinary process of puddling and that of Bessemer. In further confirmation of the preceding statements concerning sulphur and phosphorus, I present the following

[4] Comptes Rendus. 1863. Août. 57. p. 316.

[5] Cited by Colonel Eardley Wilmot, R.A., on the discussion of Mr. Bessemer's paper at the Institution of Civil Engineers.

analyses by Mr. Tookey of the pig-irons and the Bessemer irons made therefrom:—

	Pig-iron. Per cent.		Bessemer Iron. Per cent.
Carbon	3·309	...	0·218
Silicon	0·595	...	none
Sulphur	0·485	...	0·402
Phosphorus	1·012	...	1·102
Carbon	3·383	...	0·281
Silicon	1·630	...	none
Sulphur	0·206	...	0·371
Phosphorus	1·090	...	1·966
	Indian Pig-iron.		
Carbon	3·97	...	0·09
	Acadian Pig-iron.		
Carbon	3·91	...	0·04

In order that the Bessemer process should be generally applicable in this country, it must be supplemented by the discovery of a method of producing pig-iron sensibly free from sulphur and phosphorus with the fuel and ores which are now so extensively employed in our blast-furnaces. The problem may be difficult of solution, but surely it is not a hopeless one. It will not be solved by the patented process of a Mr. Anthony Bessemer, which consists essentially in exposing molten pig-iron to the action of atmospheric air or steam, or even "pure oxygen gas" (what a magnificent pyrotechnic effect it would produce!) in a cylindrical revolving reverberatory furnace.[6] The improvements of this patentee "are intended to cleanse the pig or crude iron from all (!) its impurities, such as sulphur, phosphorus, silica (*sic*, so spelt also in the provisional specification), carbon, &c., and all other foreign matter, so as to produce steel and malleable iron."

Fremy, in a recent communication to the French Academy, announces that he has succeeded by means of Bessemer's process in producing first-rate steel from French pig-irons, smelted with coke, and from which previously good steel could not be obtained. The method is not revealed; and it is somewhat surprising that a scientific body like the Academy should receive papers of this kind. Numerous specimens of steel, alleged to have been manufactured according to Fremy's improved process, were exhibited to the Academy; but it may be reasonably doubted whether the Academicians had sufficient practical knowledge of the subject to form any satisfactory judgment as to the quality of the specimens of steel thus presented to their notice.[7]

In the paper read before the Institution of Civil Engineers, Mr. Bessemer described the process of puddling, and finally pointed out its obvious imperfections, which were previously well known. He properly asked, "Why should it be attempted to stick dirty little

[6] Improvements in the manufacture of iron and steel, and in apparatuses (*sic*) to be employed therein. A.D. 1858, Oct. 5. No. 2207.

[7] Comptes Rendus. 1862. 55. page 297.

granules of that metal [iron] together, and then to squeeze the impure mass, until it is so small as to be useless, until it is again fagoted up and imperfectly united, and thus for ever to multiply the defects which its first treatment entails?" There is a ready and sufficient answer, namely, at present no alternative is known. Bessemer's process is powerless to convert ordinary kinds of pig-iron into merchant iron of the least value; whereas this is every day accomplished by the old and barbarous method of puddling. With the exception of certain varieties of red hæmatite, all our iron ores contain a sensible amount of phosphoric acid, of which, practically, the whole of the phosphorus passes into the pig-iron smelted from them. The proportion, however, raised of the former is small in comparison with that raised of the latter; but it is only with pig-iron, practically free from phosphorus, that Bessemer can deal satisfactorily, and such pig-iron forms merely a fraction of the total produced in this country. It will be time enough for Mr. Bessemer to sneer at puddling, when he can show how that laborious operation may be dispensed with. He has not yet done so.

We are informed that "Nothing but a profound conviction on which the process was originally based, could have induced Mr. Bessemer and his partner, Mr. Longsdon, to set aside, for years, every other pursuit, and to follow it up, through all the tortuous paths of chemical and practical investigations, and through the numerous trials, difficulties, failures, and expenses, that ever attend the practical development of any new system." No one is more willing than the author of this work to concede to Mr. Bessemer what his ingenuity and perseverance justly entitle him to expect. But the manner in which Mr. Bessemer refers to the chemical part of the investigation might lead to the inference that this had been conducted exclusively either by himself or his partner. He has, however, received valuable aid from more than one expert analyst, which it would have been generous on his part to have acknowledged before such an audience as that of the Civil Engineers.

In the discussion which followed the reading of Mr. Bessemer's paper, some singular remarks were made, particularly by Mr. T. M. Gladstone, who informed the audience that he, "under the late Mr. Edward Thorneycroft, had gone through the whole process of iron manufacture—that in the process as described, there was *not one step in advance, nor anything, in fact, which had not been previously done by the manufacturers of Staffordshire.* . . . Iron had been made so pure [*i. e.* by the ordinary processes of refining and puddling], that *a magnifying-glass failed to reveal the presence of any impurities.* The Bessemer process only brought the metal into the same condition in which it was left by the refinery, before being put into the puddling furnace. The quality of the metal was no doubt improved, by its *affinity for oxygen*, which was an *expensive fuel*, used for its conversion." The italics are mine. However thoroughly this speaker may have "gone through the whole process of iron manufacture," it is obvious that he displayed sad igno-

rance of the science of his art. The idea of seeking for impurities like silicon, sulphur, and phosphorus, or other than such as are mechanically interposed, in iron by means of a magnifying glass, has, at least, the merit of originality. It reminds me of an anecdote concerning the detection of iron in a mineral water. A gentleman, residing near Dudley, went into a so-called chemist's shop, in order to have some water tested for iron, when the sapient compounder of drugs immediately applied the magnet! The assertion that Bessemer's process is not a step in advance, must have arisen from an entire misconception of its nature and object; or, possibly, from some other cause. The statement as to the improvement in the quality of iron "by its affinity for oxygen" is on a par with the designation of oxygen as a "fuel."

Description of the Apparatus.—For the working drawings from which the accompanying engravings have been executed, and for details of the manipulation, I am indebted to Mr. John D. Ellis, of the firm of Messrs. John Brown and Company, of the Atlas Works, Sheffield.

Two converting vessels are worked, each capable of producing 3 tons of steel at one operation. The apparatus employed for the production of steel by the Bessemer process consists essentially of a converting vessel termed the "converter," mounted on trunnions, an hydraulic apparatus for moving the converter, and a blowing engine. In the accompanying figures the converting vessel and the apparatus for moving it are shown in side and end elevation, as well as in vertical and horizontal sections. (In order to simplify the drawing in the side elevation, the hydraulic tipping apparatus is represented as if in front of the converting vessel: its true position is, however, to be seen in the plan and end elevation.)

The converter is an ellipsoidal vessel, made of wrought iron, in two principal portions, flanged and bolted together, flat bottomed, and terminated above by an oblique conical mouth. It is supported by a central wrought iron belt furnished with trunnions, of which one is connected by a coupling box with the pinion of the turning apparatus, while the other is hollow, and in communication with the blast pipe. The body of the converter is lined inside with a thick coating of a mixture of fire-brick and ground "ganister," a variety of refractory sandstone from the lower coal-measures of the neighbourhood of Sheffield. This mixture is stamped in a moist state round a wooden core, which is afterwards removed; it is then slowly dried, and any cracks are made good. It need hardly be observed that each half is lined separately. When dry, a fire is made in the interior, and a gentle blast supplied, so as gradually to raise the temperature. Mr. Bessemer states that he then throws in a little salt, in order to render the lining more compact, by a glaze similar to that of common earthenware. Into the bottom of the vessel is fitted a series of round fire-bricks or twyers, each eighteen inches deep, about four inches in diameter, and perforated by seven or more holes. In a 4-ton converting furnace, seven of these bricks are employed; they are arranged sym-

metrically as shown on the plan, the spaces between them being carefully filled in with ganister.

The machinery for giving motion to the converter consists of a double-acting water pressure engine, with a horizontal cylinder, the piston-rod of which is terminated by a rack, gearing into a pinion.

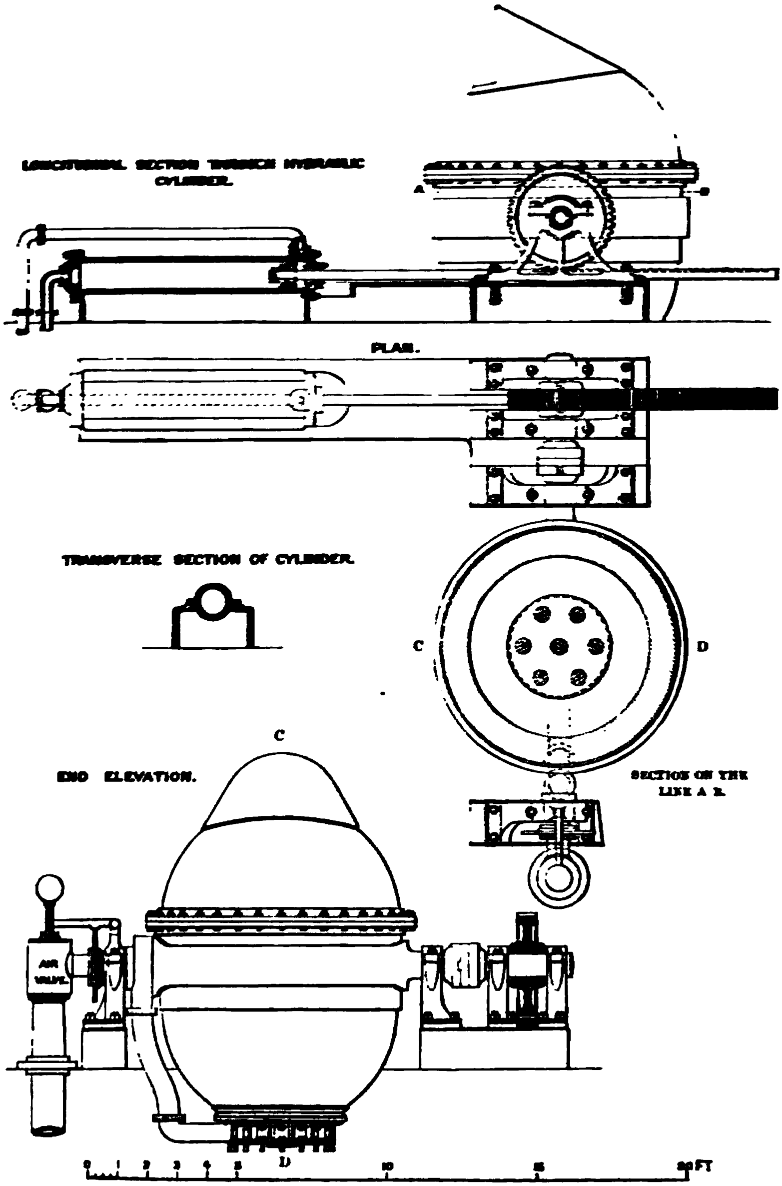

Fig. 212. Bessemer Converting Vessel.

which is connected by a clutch with the hinder trunnion. Accordingly, as the water is admitted on the front or back of the piston, the converter is tilted from a vertical to an inclined position, or the reverse.

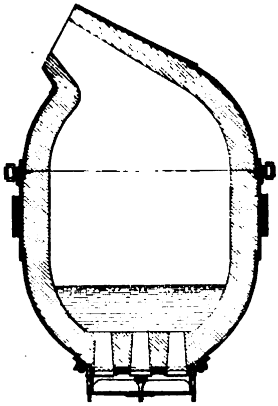

Fig. 213. Vertical Section of the Converter on the line C D, fig. 212.

The blast is admitted through the regulator valve (shown in the end elevation); it passes through the trunnion, which is hollow, and enters the twyer, along the bottom of the converter, by a curved branch pipe, united above to the trunnion-belt.

At the Atlas Works the process is conducted in the following manner. The charge of pig-iron (that smelted from Whitehaven hæmatite being the most suitable), weighing about 3 tons, is melted in an air-furnace, the bed of which is above the level of the converting vessel; the latter is then turned to a horizontal position, with its open mouth upwards. The air-furnace is tapped, and the charge of molten pig is run through a trough lined with sand into the converter, filling it nearly up to the level of the twyers; the blast is turned on, and the converter is swung slowly back to the vertical position. A pressure of blast of 15 lbs. to the square inch is employed, with a converting vessel of 42 inches internal diameter, having 49 holes, each ½ an inch in diameter, the charge varying from 3 to 4 tons. The blowing engines are driven by a pair of horizontal steam engines, with pistons 16 inches in diameter and 24-inch stroke, working with steam of 40 lbs. pressure.

The blowing is continued from 12 to 20 minutes, according to the quality of the pig-iron operated upon; when the proper stage of decarburization has been reached, the converter is turned back to the horizontal position, the blast is shut off, and from a small furnace a specific quantity of molten spiegeleisen, usually from 5 to 10 %, is run in; the blowing is then resumed for a period of five minutes, in order to effect thorough incorporation of the spiegeleisen with the original charge; the converter is then lowered again, and its entire contents are run into a ladle, from which the ingot moulds are filled.

The ladle is lifted by hydraulic power, derived from the same pair of pumps which give motion to the tilting apparatus of the converter. A vertical ram is placed below the level of the casting-pit, carrying on its upper end a strong radial arm, which embraces the ladle; this arm revolves freely from the top of the ram, and permits the ladle to be brought into position over the mouth of each of the moulds in succession.

The ladle is made of wrought-iron, measuring 42 inches in diameter and 4 feet in depth; it is lined with sand, and is provided with an iron plug, also coated with sand, the lower end of which is fitted into a socket at the bottom of the ladle. When the plug is raised the molten steel flows out in a stream of about 1 inch in diameter

into the mould. When the ingots have cooled they are ready for hammering.

The loss of weight during the conversion amounts to about 15 °/° of the original weight of the pig-iron employed, in addition to which the charge loses about 7½ °/₀ of its weight in the preliminary fusion in the air furnace. The converting vessels will blow about 250 tons of metal without relining; the twyers have to be renewed after about 10 tons of steel have been made.

Mr. Ellis observes, "statements have been made which have led the public to believe that steel by this process can be made at very low prices; but our experience has proved that it is necessary to use a much more expensive class of pig than was ever contemplated by Mr. Bessemer, and that ingots cannot be produced at less than 10*l.* per ton." (September 11th, 1863.)

Parry's Process of Manufacturing Iron and Steel.

A patent was granted for this process in 1861 to Mr. George Parry, of the Ebbw Vale Iron-works.[a] I have previously alluded to this process, when treating of the elimination of phosphorus during the process of puddling. Wrought or malleable scrap iron is converted into cast-iron in a cupola, similar in construction to those commonly used in melting pig or cast iron in foundries, with the exception, that opposite to the usual horizontal twyer there is a second twyer inclined downwards at an angle of from 30° to 35°. The effect of this inclined twyer is to produce an extremely high temperature in the lower part of the furnace.

"This invention has for its object the production of a superior bar or wrought iron to that obtained in the ordinary manufacture of iron, as well as the production of cast-steel in large masses of a superior quality to that obtained by the direct decarbonization [decarburization] of crude pig-iron, as now carried out. To accomplish these objects I take wrought-iron, which from having previously undergone the puddling process, has been purified by the expulsion of sulphur and phosphorus; or I take wrought-iron scrap and introduce it, together with coke or other fuel and proper fluxes into a blast-furnace similar in form to that ordinarily used for melting pig-iron, but so arranged with respect to the twyers as to ensure the maintenance of a much higher temperature in the furnace than is required for merely melting the iron. By this means I am enabled to effect the rapid and economical carbonization of the wrought-iron under treatment. When thus carburetted I run out the iron from the converting or blast furnace into any suitable form, and submit it to the puddling process, by which means a further portion of sulphur and phosphorus is removed and the iron is increased in strength and value. This iron may, if thought desirable, be again carbonized and puddled again for the third time.

[a] Improvements in the manufacture of iron and steel. A.D. 1861, Nov. 18th. No. 2900.

"In carbonizing the wrought-iron I propose to make it take up two per cent. or thereabouts of carbon from the coke, when it will be ready to undergo the subsequent treatment of puddling, which will convert it into what I term 'purified wrought iron.' Sufficient fuel having been supplied to the furnace for the purpose of getting up the heat, I charge the furnace with about seven hundredweight of coke (with sufficient lime to flux the ash of the coke) to every ton of wrought iron, applying these materials in successive quantities of from one and a quarter hundredweight to one and a half hundredweight of coke to four hundredweight of iron, which will be found a convenient quantity for each charge. The converting furnace being filled and the blast put on, the furnace should be kept nearly full during the continuance of the operation, or the iron will not have taken up a sufficient dose of carbon, and unless this be done the subsequent treatment of the iron in the puddling furnace will be useless; the presence of a certain amount of carbon in combination with the metal being necessary to produce the 'boil,' without which no efficient refining of the iron will take place. With a small furnace two and a half feet square, rounded at the angles, and from ten to fifteen feet high, blown by one horizontal twyer having a nozzle of two and a half inches diameter, and one inclined twyer of one inch and a quarter diameter; with a pressure of blast of two pounds and a half to three pounds on the square inch, I have been enabled to carbonize and run out one ton of iron per hour. In carrying out this part of the process I prefer to blow down into the iron through one or more twyers, not using the lower twyers. The nozzles of these twyers may be changed for others of larger or smaller bore in a few seconds when required; the exact amount of blast required being soon ascertained by a little practice, the want of a sufficient blast being indicated by the carbonized iron when run off not being sufficiently fluid. With converting furnaces of larger dimensions the number of both horizontal and inclined twyers must be increased so as to diffuse the blasts of air more uniformly over the enlarged area of the furnace. The whole of the twyers may be inclined downward with nearly the same effect, if thought desirable; but must be put at a lesser angle of dip. I prefer, however, the mode of blowing, as above described. There is little or no loss of metal in carrying out this carbonizing process when clean wrought iron is employed; the small quantity of iron oxidized, and which passes off with the slag, being replaced by carbon. The minute portion of silicon in this carbonized wrought-iron, as compared with that contained in crude pig-iron, does not admit of slag being formed to any extent when air is blown into it while in the fluid state; but the oxide formed would pass out at the top of the furnace as a dense brown smoke, and entail a loss were it not that the column of incandescent fuel above reduces it to the metallic state and intercepts it. I find that a height of furnace from eight to ten feet is sufficient to effect this reduction, and prevent the loss of metal by sublimation.

"When the charge of scrap or puddled iron has been subjected to the blast a sufficient time to bring down, say a ton of the carbonized

metal. I tap the furnace, and run the metal into moulds as is usually done with pig-iron intended for puddling, and I otherwise treat it in a similar manner to iron prepared for puddling (that is to say), I now submit the carbonized, wrought, or scrap iron to the operation of puddling in an ordinary puddling furnace, and by that means cause it to give up or part with the impurities remaining therein, after the first puddling process. The metal I remove as puddled balls, which may then be submitted to the ordinary rolls, for the purpose of being reduced to the form of merchant or other bars. This completes (in general) the process of making my 'purified wrought iron,' which may be subsequently converted into cast-steel in the manner presently to be described, or applied to other uses. When, however, a still purer quality of iron is required, I repeat the converting or carbonizing process, and then subject the metal to the puddling process as before.

"I would here remark that by taking the thoroughly puddled iron from the furnace in small balls or pieces, the cost of rolling the same into bars, and cutting those bars up by shears into pieces suitable for undergoing a second carbonization, or for conversion into hard or soft steel will be avoided. The pieces of wrought-iron intended for carburation should not be too large, not much exceeding the size of a railway bar cut up into lengths of four to six inches. Cinder iron, of which nearly the whole of the railway bars laid down have been manufactured, becomes by sufficient carburation in my converting furnace, and subsequent puddling, equal in value to the best brands of mine-iron, and may be used for the like purposes, or be converted into cast steel; thus the iron rails now in use, as they successively become worn out, may by this Invention be converted into durable cast-steel rails.

"In order to convert bar or scrap iron into cast-steel, I introduce into the converting or blast furnace, a smaller proportion of coke or fuel than is required for manufacturing the purified wrought-iron. The proportion may be so regulated, as to communicate to the wrought-iron the desired degree of carbon known to exist in the various classes of cast-steel, from hard cast-steel to soft cast-steel, and I run this steel out of the furnace into ingots, or into any desired forms.

"In the manufacture of cast-steel from wrought-iron, I use the same kind of converting furnace as that described for making the more highly carburretted metal; but I reduce the quantity of coke to about five hundredweight to every ton of wrought-iron used when making a hard steel, and to about four and a half hundredweight when producing a soft steel, the proportions varying somewhat, according to the quality of the coke or other fuel used. In making hard steel, I increase the size of the nozzle of the blowing down twyer, making it about one and a half to one and three-quarters inches in diameter, so as to discharge more blast into the metal at the bottom of the furnace than is required when preparing the carburetted iron for the puddling process. The proper quantity of air required will be found by a little practice, for if too little be blown down, the steel will prove deficient in fluidity."

In the specification two methods are described for making what is termed "soft steel," one in which the softening is effected in the cupola itself, and the other in which it is effected in a separate vessel or receiver; but the latter only is now adopted. The receiver is an oval-shaped vessel of wrought-iron, flat at the bottom, lined with refractory material, such as a mixture composed of equal measures of fireclay and sand. It is open at the top, and on one side near the top is introduced a large jet of combustible gas (such as is formed in an ordinary gas-generator) and atmospheric air. Round the lower part of the vessel, just above the bottom, are adjusted five blast boxes, each containing three twyers for the injection of atmospheric air. There is also a tap-hole at the bottom by which the molten metal is run off. The receiver having been heated by means of the gas-flame to bright-redness, and the blast let on through the twyers, the molten steel to be softened is allowed to flow into it from the cupola.

"I first make a hard steel in the converting furnace, and then run it out into another furnace or receiver, where I reduce it to the required degree of softness by passing air through the fluid metal from below, as first pointed out in the specification of Mr. J. G. Martien's patent, dated Sept. 15th, 1855 (No. 2082), for the treatment of crude pig-iron, or I blow air down on the surface of the metal as practised in the old refineries, and should the steel now be found too soft for the purpose required, I harden it by the addition thereto of a proper proportion of the hard steel in a fluid state from the converting furnace.

"After a few minutes blowing into the receiver (the exact time requisite being very accurately ascertained by the workman after a little experience) the steel will have become sufficiently softened, and may be tapped and run out into a funnel and dealt with as before described. Previously to tapping the furnace alloys may be run in at the top, or what is better the alloying material may be poured into the funnel as the steel is running. It may also be hardened when made too soft by the addition of hard steel or of any pure pig or carburetted iron (which may also contain the alloy) in the same manner."

The advantages claimed by the patentee in this process are stated as follows :—

"In the manufacture of cast-steel direct from crude pig-iron, as lately introduced by removing a portion of the carbon, sulphur and phosphorus remain behind, and it is difficult to get crude pig-iron free from these injurious elements. In this my process for manufacturing cast-steel by adding carbon to wrought-iron (which had previously been puddled) nearly all the pig-iron produced in this country becomes available for the manufacture of cast-steel in my converting furnace, the greater proportion of the sulphur and phosphorus originally contained in the iron having previously been eliminated in the puddling process.

"From some years' experience in the analysis of irons, I have always found that the effect of puddling is to reduce the quantity of sulphur to about one-third, and of phosphorus from one-fourth to one-fifth of

that originally contained in the pig-iron. It will thus be seen that when such purified iron has been sufficiently carburetted in my converting furnace and again puddled, the impurities above named become almost entirely removed, and the iron is fitted for conversion into best cast-steel by this invention."

Now, it is important to observe, that the materials upon which Mr. Bessemer operates are restricted to three, namely, crude pig-iron as it flows from the blast-furnace, remelted pig-iron, and refined iron. No other materials are mentioned in any of Mr. Bessemer's numerous specifications. But Mr. Parry does not deal with any of these materials; for clearly the carburized iron, into which he converts wrought or malleable scrap iron in the cupola, cannot be designated either as crude pig-iron from the blast-furnace, as remelted pig-iron, or as finery iron. It is a fusible compound of iron and carbon *produced from wrought-iron.* There is no other method, so far as my knowledge extends, by which either wrought-iron or steel practically free from phosphorus can be derived from pig-iron containing a sensible amount of that element. It remains to be seen whether Mr. Bessemer will venture to attack this patent on the ground of infringement. Should he do so, we may reasonably anticipate interesting and protracted proceedings in the courts of law.

Casting Steel.

Formerly, so far as I am aware, steel was never melted and cast after its production; and, in only one instance, namely, that of wootz, was it ever molten during its production. By whatever method prepared, whether by the addition of carbon to malleable iron, or by the partial decarburization of pig-iron according to any of the methods described, except those attended with absolute fusion of the product, steel in mass was never obtained homogeneous. When made even by the cementation of bar-iron, certain defects in the manufacture of the iron, especially such as depend on the presence of intermixed cinder, were perpetuated in a greater or less degree in the resulting bar-steel. And without fusion, it is, for reasons previously assigned, impossible that it should ever be otherwise. In bar-iron want of homogeneity or unsoundness due to the interposition of cinder is of much less consequence except, perhaps, in the case of fine wire-drawing, etc., than in steel, which is to be fashioned into articles with fine cutting edges. Now, by the fusion and casting of steel after its production, the evil in question is remedied, and ingots of the metal may be thereby procured of perfectly uniform composition throughout; and for the practical solution of this important problem we are indebted to Benjamin Huntsman.*

* The fullest account which I have met with of this inventor is in an excellent essay on steel manufacture, by an anonymous author, in the volume entitled The Useful Metals and their Alloys. London, 1857. pp. 840-849. But it is stated in the preface that the details concerning Huntsman's discovery of cast-steel were communicated through another channel. Le Play, in a note to his memoir, "Sur la Fabrication de l'Acier en Yorkshire" (Annales des Mines, 1843, 4 s. 3. p. 638),

This inventor was born in Lincolnshire in 1704, and died in 1776 at Attercliffe, in the parish of Sheffield, where he was buried in the Old Churchyard. Originally he was a clockmaker at Doncaster; and what is singular, it is stated that he had a high reputation as an oculist and for his medical knowledge. He afterwards resided at the village of Handsworth, near Sheffield, and there his experiments on casting steel seem to have been conducted. About 1770 he removed to Attercliffe, where his successors still conduct the business. Huntsman was a member of the Society of Friends, and was not, we are informed, "of a disposition to make the greatest commercial advantage" of his invention, caring "little for mere money making." He exhibited, however, the worldly wisdom of keeping his process rigidly secret as long as possible. "But he never," it is asserted, "condescended to push business by any of those arts which are now so common." Huntsman's steel has acquired a world-wide renown, and deserves a conspicuous place in the annals of British invention.

According to the popular tradition of Sheffield, possession was obtained of Huntsman's secret by the knavish and heartless trick of a rival steelmaker. This person, it is reported, presented himself in the garb of a beggar at the entrance to the Attercliffe Works, under conditions most calculated to excite the sympathy of the workmen; it was during a dark winter's night, when the snow was falling fast, that this mean and skulking vagabond prayed for shelter and warmth in the casting-house. The prayer was granted,—who could have refused it? —and at length the prize was secured.[1] This may be a mythical story, or it may be absolutely true: many a time the same kind of artifice has been resorted to. It is a low theft, which no man having the least feeling of honour could possibly commit. Not long ago in London an example occurred, which attracted much attention. Three persons, *all foreigners*, conspired to obtain access to works, where aniline was being largely manufactured for the production of the now well-known beautiful mauve and Magenta dyes. As usual, a conference was held at a public-house with one or two of the chief workmen, who apparently consented to aid in the plot. The night which had been appointed for the execution of this plot arrived: one conspirator entered, but the other two, whether from some misgiving or cowardice, remained where they could, if necessary, make a hasty retreat. All was dim, if not actually dark; but no sooner had the leader fairly entered, than the gas was turned full on and he stood confronted and dismayed before the proprietors of the works. He was tarred from head to foot, and sent adrift in the street crying for mercy and seeking protection from the police. He was confined to his bed several days in consequence of the severe irritation to his skin. He

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gives the dates of Huntsman's birth and death, which he himself copied from his tombstone in the graveyard at Attercliffe; and it is somewhat singular that he should spell the name Huntsmann. The inscription on the tombstone has been copied for me by my friend and former student, Mr. William Baker, and is as follows: "Sacred to the memory of Benjamin Huntsman, of Attercliffe, steel-refiner, who died June 20th, 1776, aged 72 years."

[1] The Useful Metals and their Alloys, p. 348.

was [illegible] secret, and would that every [illegible] of the like [illegible] had been taught and treated in the same way. The other [illegible] in [illegible] attempt to [illegible] unless men of the [illegible] of their [illegible] treated [illegible] with [illegible].

With reference to the invention of cast-steel, Horne, in 17[illegible], published a singular and to some extent erroneous statement.[1] "It is not," he writes, "a great many years since this discovery of cast-steel was first made by a gentleman, as I have been informed, residing in the Temple, an acquaintance of the late Lord Macclesfield, whose name I could never learn, nor could I ever gain the least information of the means by which he became possessed of so valuable a secret. He, however, judged it proper not to let it remain a secret any longer than till an opportunity offered of discovering it to some person who, he imagined, might be able to render it of service in some shape or other to himself as well as to the world. While the gentleman was thus inclined, there fell in his way one who had been employed in forging of gold and silver wire for the use of the lacemen; whom he judged to be a proper person for his purpose. Prior to this period the workmen, at a very considerable expense and no small risk, had been obliged to smuggle those implements, or wire-rollers, by which the wire is flatted, from Lyons, in France; whereas our melted steel is qualified to form them in a much better manner; but still liable to this considerable objection; that as the steel is obliged first to be forged into plates, there is an absolute necessity of their being welded in one particular part, which not only injures the steel when they are bent round the iron roller, but leaves a disagreeable roughness upon that part where the welding heat must of necessity be administered."

The present method of casting steel is substantially the same as that practised by Huntsman, the difference, it is stated, being that now two crucibles instead of one are heated in each furnace. For the drawings, from which the accompanying engravings have been executed, I am indebted to my friend, Mr. E. F. Sanderson, of Sheffield. They will be sufficiently intelligible without any particular description. Fig. 214 is the ground plan of the casting-shop. Fig. 216 is the basement plan. Fig. 217 is a transverse vertical section of the same. Fig. 215 is a longitudinal vertical section of the same. The furnaces, it will be perceived, are simple rectangular chambers, each having its own flue in the stack common to a row of furnaces. The tops of the furnaces are on a level with the floor of the casting-shop; and at the bottom they are easily accessible from the cave below. The furnaces are covered over with cast-iron plates, about 1 in. thick, in the manner shown in the First Part of this work (p. 455), and each is provided with a moveable cover, consisting of a quarry or large fire-brick, let into a strong wrought-iron frame, from which a round wrought-iron handle projects horizontally, or nearly so, from the middle on one side (fig. 218). Coke is the fuel employed. The furnaces are lined either

[1] Essays concerning Iron and Steel, p. 165.

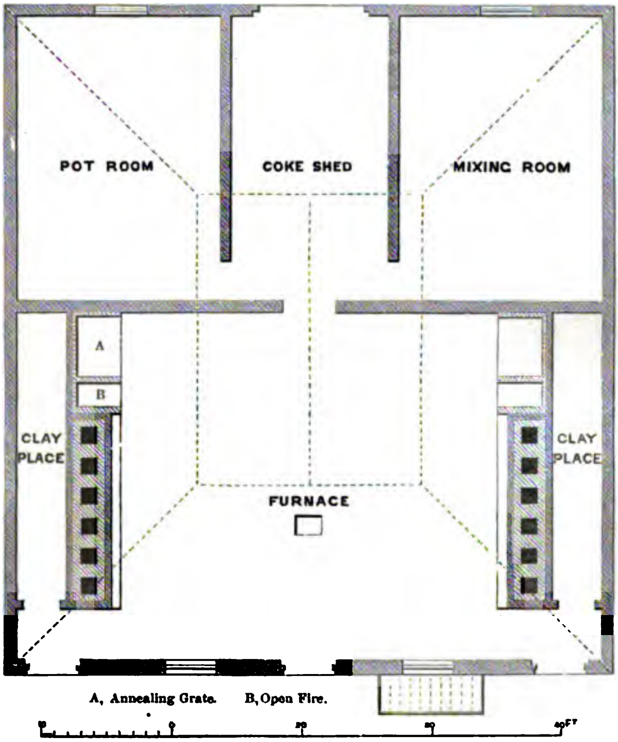

Fig. 214. Ground plan of the casting-shop.

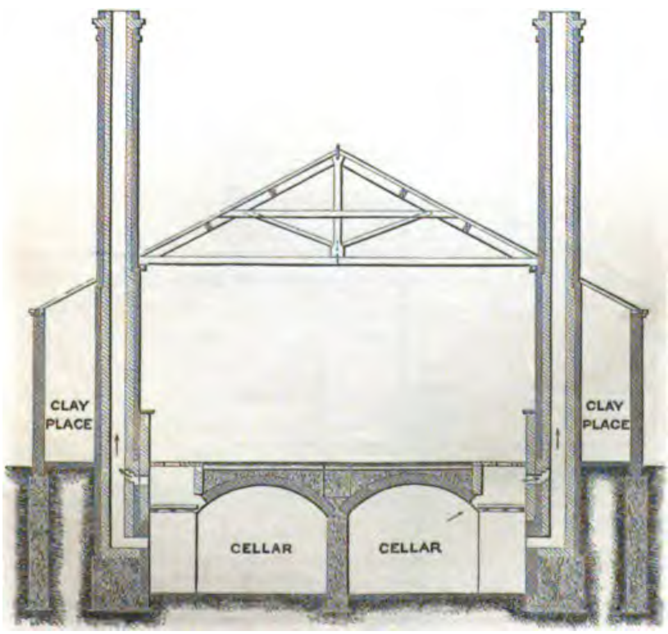

Fig. 215. Longitudinal Vertical Section.

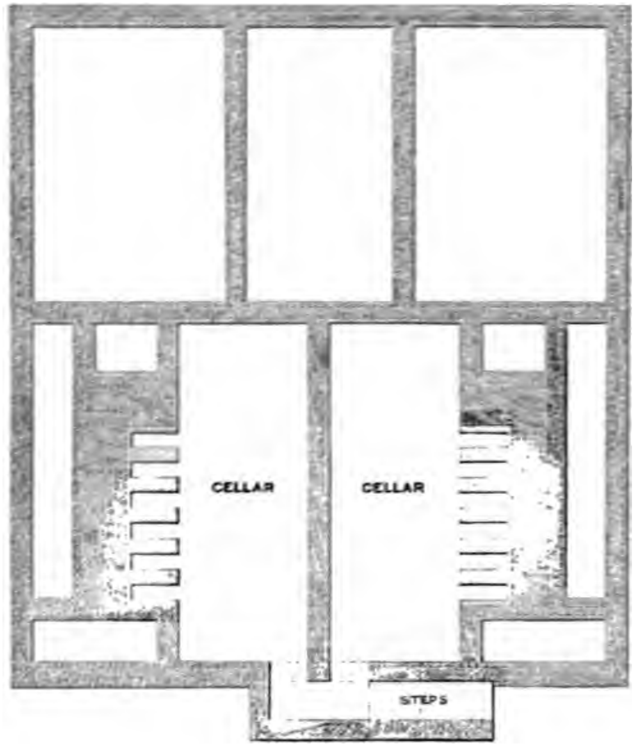

Fig. 216. Basement Plan.

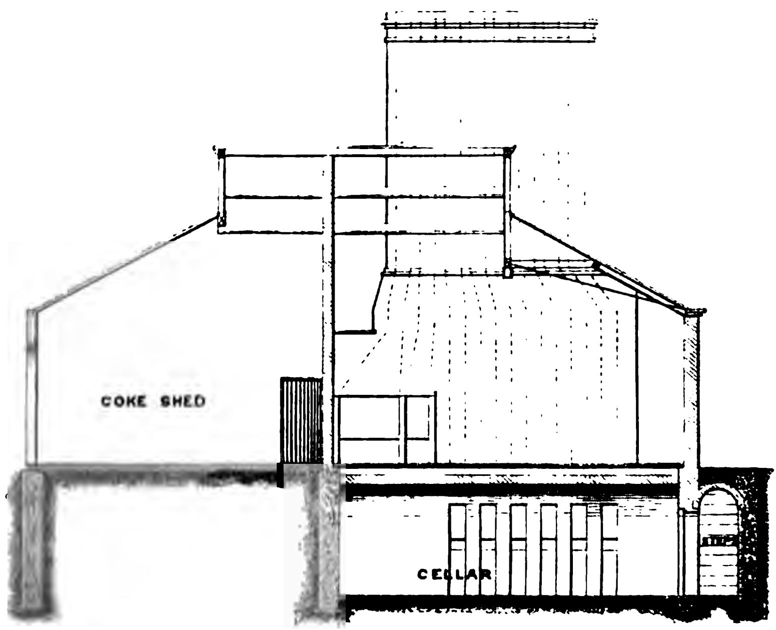

Fig. 217. Transverse Vertical Section.

with fire-clay bricks, or a siliceous stone occurring in the neighbourhood of Sheffield, or ground "ganister;" millstone grit tempered with water is also used. A mould is put into the furnace, and the mixture rammed round it, after which the mould is taken out.

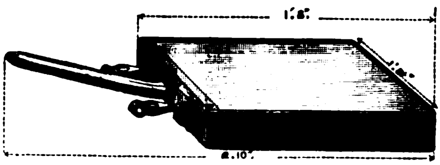

Fig. 218. Moveable cover of casting-furnace.

The crucibles, or, as they are usually termed, pots, are made in moulds, similar in construction to the little Swedish mould for iron-assay crucibles, described in the First Part. It consists of a circular cast-iron case or "pot-mould," open at top and bottom, and turned in the interior of the same dimensions as the exterior of the pot. It has two projecting pieces, one on each side, by which it may be conveniently lifted. In this case fits a plug of hard wood, such as lignum-vitæ, turned of the same dimensions as the interior of the pot; on the top is a head of iron to receive the blows of a mallet, and in this head is a transverse hole, through which an iron pin may be passed to serve as a handle for turning the plug round; from the bottom of the plug an iron spindle protrudes. In the pot-mould is a loose disc of iron, just large enough not to drop out at the lower or small end, and having a hole in the centre for the passage of the spindle. The pot-mould being well smeared with whale-oil, is placed upon a low post solidly fixed in the ground, and having a hole in the middle to allow the spindle of the plug to descend. The charge of clay, in the form of a short cylinder, is put into the pot-mould, and the plug, also well oiled, is then driven 2 in. or 3 in. down by means of a heavy mallet, the spindle at the bottom keeping it in the centre. The plug is then withdrawn with a screwing motion by means of the moveable pin in the head, as above described; after which it is oiled afresh, again inserted, and driven home, the clay rising in the space between the plug and the interior of the pot-mould. The clay is cut level with the top of the mould with a knife, and the plug is taken out of the pot. The top is then narrowed somewhat by inserting a

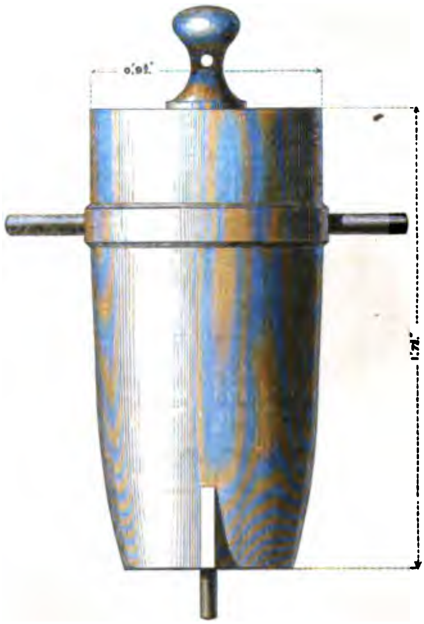

Fig. 219. Crucible-mould.

[illegible] and the corresponding part of the pot-mould and [illegible] the centre. The pot-mould is then set upon a short post, so that its loose bottom may be gently forced up with the pot upon it. The pot is then removed to a warm place to dry.[3]

Fig. 220. Section of crucible-mould.

The lids are made of the same material as the pots. They are circular, a little larger in diameter than the mouth of the pots, flat on the under side, and somewhat convex on the upper side. The stands also are made of the same material as the pots. They are circular, but a little narrower at the bottom, where they rest immediately upon the bars.

The pots used at one of the chief establishments in Sheffield weigh about 25 lbs. each, and are made of the following mixture :[4]

Derbyshire clay from Edensor	15 lbs.
Stannington clay	7 ,,
Old ground pot	2 ,,
Ground cinders	1 ,,
	25 lbs.

Fig. 221. Crucible, cover, and stand.

My friend and former student, Mr. William Baker, of Sheffield, has at my request procured for me the following information. The raw clay, as it is delivered to the works, is shot down behind the furnaces to be thoroughly dried. The "falling of the clay," *i. e.* mixing it with water, is effected in a large cast-iron cistern. The quantity of clay operated upon is determined by the number of pots to be made. Ground coke-dust is added in the proportion of from 1½ lb. to 2 lbs. for 20 lbs. of the dry clay. When thoroughly soaked, the clay is removed to

[3] Vid. Useful Metals and their Alloys, p. 310, for a good description of pot-making, from which I have taken a few details.

[4] Analyses of the clays have been given in the First Part of this work.

the treading floor, where it is kneaded by men treading upon it barefoot during 8 or 10 hours. It is thus spread out, so as to form a layer 2 in. or 3 in. thick, which is cut across and across with a spade into rectangular pieces, each of which is turned over on its neighbour, forming a number of blocks. The clay is weighed out in lumps, one of which suffices for a pot. To form a pot capable of holding 28 lbs. of steel, 24 lbs. of clay are required. A man will make 20 pots per day. The pots vary in size, some holding from 28 lbs. to 30 lbs., and others from 45 lbs. to 50 lbs. of steel. They are left to dry during 8 days previously to use. They cost on the average about 8*d*. each.

The pots are annealed, *i. e.* gradually heated to redness, before they are put in the casting furnaces. About 20 pots are generally placed mouth downward on the "grate," containing live coal, and coke is then filled in between them. The lids are placed on the bottoms of the inverted pots. This is done over night or in the afternoon. At 5 or 6 next morning the pots thus heated are placed upright with their lids adjusted, on their stands in the furnaces, previously charged with live coal from the fireplace at the side of the "grate," where the annealing is effected.

One or two pots, as the case may be, previously "annealed," are placed in each furnace, and a handful of sand is thrown into each pot to stop up the hole left by the spindle of the plug used in moulding. The pots are then "brought up," *i. e.* raised to a high temperature, and in about 20 minutes a charge of broken up and assorted blister-steel of from 30 lbs. to 40 lbs. in weight is introduced through a funnel-shaped charger of sheet iron, and the mouth of the pot is then closed with a clay lid, and the furnace filled up with coke. After the lapse of ¾ hour, the furnace is again replenished with fuel. In another ¾ hour, the foreman takes off the lid of the pot to examine the progress of the melting; and, according to his judgment, more or less coke is added to complete the process. When manganese is used it is added along with the steel. As soon as the steel is perfectly molten, and ready for "teaming,"[5] the "puller out," having enveloped

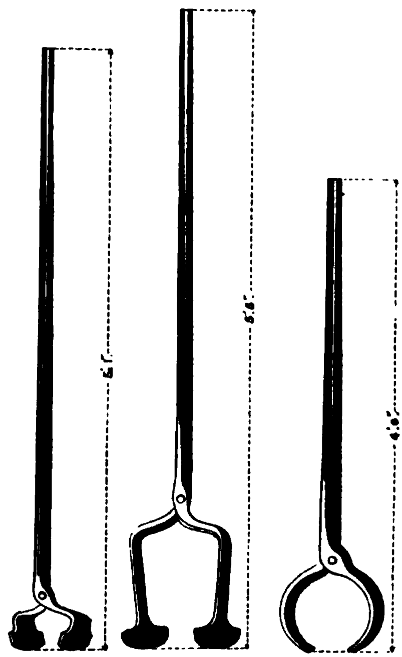

Fig. 222. Tongs. Tongs for lifting. Tongs for "teaming."

[5] A word commonly used in the midland counties for pouring.

his legs in sacking and freely besprinkled them with water, stands over the furnace hole or mouth, whilst the "cellar lad" loosens the pot from clinker adhering to the bottom of the furnace. With one good hoist the pot is transferred to the "teaming hole," a rectangular cast-iron box about 18 in. square and of the same depth, let into the floor of the casting shop, and having a quantity of coke dust on the bottom, so that the pot may be prevented from coming in contact with the iron and cracking in consequence. The lid is removed and placed on the pot which has just been teamed, which is then immediately returned to the furnace. The chief melter now takes hold of the pot with the "teaming" tongs, and pours out the steel, taking care to avoid touching the sides of the mould. If any slag appears on the point of issuing with the steel, a boy takes the "flux stick," a rod of iron with a ball of slag purposely left adhering to its end, and touches the surface, when a remarkable repulsion of the matter forming the slag takes place and it flies back to the bottom of the pot. Sand is thrown on the top of the ingot, and a stopper put on it, *i. e.* a lump of iron fitting the mouth of the mould, and having a handle 8 in. or 10 in. long.


Fig. 223. Charger.

A pot will last three meltings, but each time with a diminished charge: thus, in the 1st charging, it may receive 45 lbs., in the 2nd 40 lbs., and in the 3rd only 36 lbs. The furnace needs repairing once a month. The ingot moulds are smoked before use. For this purpose their component halves are placed with their internal surfaces downwards upon racks, which consist of two iron bars about 6 ft. long each, 1 ft. apart, and 1 ft. above the floor, supported at their ends. A shallow ladle containing burning coal-tar is then put underneath. Notwithstanding the smoking, it is remarkable how the molten steel eats into the bottom of the moulds, hollowing them out considerably towards the centre; and in the case of moulds 6 in. square in section rendering the bottom honeycombed. There is great variation in the size of the moulds, according to the purposes for which the ingots are intended.

In the International Exhibition of 1862, drawings were exhibited in the Austrian department of a cast-steel furnace, constructed on Siemens's regenerative principle with brown coal as the fuel. On each side of the chamber, in which the pots are heated, is a regenerator. The furnace is successfully in operation at Mayr's Works at Kapfenberg, near Leoben, in Styria. I am informed that 20 pots, containing about 60 lbs. of metal each, may be heated at a time in one of these furnaces. The consumption of fuel is 3 parts by weight of brown-coal

to 1 of cast-steel. In six days 100 centners (18 ctrs. = 1 ton English) are melted. Great improvements in melting furnaces may be reasonably anticipated from the adoption of Siemens's method.

In the same International Exhibition, Krupp, of Essen, had an extraordinary display of enormous and marvellously sound ingots of cast-steel, and of various objects, such as rail tyres, locomotive and marine engine axles, guns, etc. He is reported to employ puddled steel, prepared in great measure from Müsen spiegeleisen, and to melt it in crucibles, each containing 70 lbs. or more of steel. If so, the organization must be carried to perfection to enable him to produce such large ingots. But, as Krupp affects considerable mystery, it is well not to place too much reliance on mere reports concerning his mode of manipulation.[6] The largest ingot exhibited by Krupp in the first International Exhibition, in 1851, weighed 2¼ tons; whereas the largest which he sent to the last, in 1862, weighed 21 tons. It was in the form of a solid cylinder, about 9 ft. high and 3 ft. 8 in. in diameter; and had been broken across to show the character of the fracture. I examined it repeatedly with the utmost care without being able to detect the least flaw in any part, even with the aid of a lens; and the grain was everywhere remarkably uniform. I was informed that the largest ingot which Krupp had ever cast weighed 25 tons. There was a rectangular ingot weighing 15 tons, which had been broken across in eight places; and in none was any unsoundness visible. The moulds for casting such large ingots were of course vertical, and were, I was assured, so constructed as to avoid the presence of angles, of which the inevitable effect, it was declared, would be to cause unsoundness, due to the retention of bubbles of air, and that it had not been hitherto found practicable to prevent these defects by any arrangement of vent-holes, owing to the rapid solidification in them of the steel. Uniformity in grain, to which I have above alluded, is not an invariable characteristic of Krupp's steel; for not long ago I received from Mr. Lloyd, chief engineer of the Navy, part of a fractured marine shaft made of this steel, which was *very much* more largely crystalline towards the centre than elsewhere.

The following is an analysis by Mr. Abel, of the Royal Arsenal, of a portion of a cast-steel gun made by Krupp:

Carbon, combined	1·18
Silicon	0·33
Sulphur	none.
Phosphorus	0·02
Manganese	trace.
Cobalt and nickel	0·12
Copper	0·30
Iron, by difference	98·05
	100·00

[6] It is stated that the contents of the crucibles are first poured into a ladle similar in principle to that described under the Bessemer process; and that there is an arrangement by which, at a given signal, the crucibles can be raised up by the stokers in the cellar.

The following singular statement has been published,[7] which must not be passed over without comment. Alluding to the manufacture of files from blister-steel, the author writes, "These [*i. e.* the pieces of steel fashioned by tilting into pieces ready for being cut into files], when ground ready for cutting, would present no outward appearance of flaws; but the cutter's chisels would often penetrate parts which were unsound, occasioned apparently by a white powder embedded in the steel: to distinguish this from the effects of imperfect welding, it was called white-loose. It was a source of great annoyance to the file-makers by spoiling the appearance of their files, and causing them to be sold at an inferior price, as wasters. They complained of it many years, yet nobody cared to apply a remedy, though it admitted of a very simple one, and the case is cited to show how difficult it is to get people to change their mode of working; when at length, about twenty years ago, Mr. Ekman, an eminent iron-master of Sweden, came to Sheffield, and was shown some files in the cut state with this fault; he expressed an opinion that he knew what it was, and could send a few bars for trial, which he expected would be free from it. He did so; they were converted, but not used until his next visit to Sheffield, when the trial was made in his own presence. The cause had been found and the remedy applied: the files were without white-loose. He then explained the cause of white-loose by saying—'In my country we use wood-ashes, in the same way that you use welding sand at your forge, when we weld blooms; and it is nothing but wood-ashes mixed with the iron. The bars I sent you I saw made, and would not allow the men to use wood-ashes.' This may be a useful hint to some other Swedish iron-masters even now." The reference, no doubt, is to Mr. Gustav Ekman, the inventor of the gas welding-furnace. Having had the opportunity of seeing Mr. Ekman in London, Oct. 1863, I interrogated him concerning the authenticity of this story, when he informed me that he had no recollection of the circumstance; and he certainly could never have assigned the presence of wood-ashes as the cause of the alleged defect, which have never been used in Sweden for the purpose; and that such defects can only be due to the interposition of cinder consisting of silicate of protoxide of iron, of which in steel the oxide becomes partially reduced by the carbon of the steel.

Fusion of steel in the reverberatory furnace.—With a view to casting steel in large ingots, it is obviously desirable to effect the fusion in furnaces instead of crucibles. Cupola furnaces cannot be employed for the purpose, even if the purest fuel, such as charcoal, were used; because the metal would be materially changed in composition by contact with solid carbonaceous matter at high temperatures. It only remains, therefore, to attempt the solution of this important problem in reverberatory furnaces, heated either in the usual manner or by the combustion of the gaseous products of gas-generators. M. Sudre, in France, has proposed the application of reverberatory furnaces to the

[7] Useful Metals and their Alloys, p. 344.

object in question, similar in construction to those in which cast-iron is occasionally melted for gun-founding or other purposes, in which the quality of the metal is of the highest importance. Accordingly, Sudre's proposal has been tested on the large scale in France by order of the Emperor Napoleon. The experiments have been conducted at the forges of Montataire, under the inspection of Treuille de Beaulieu, Colonel of Artillery, Henri Sainte-Claire Deville, and Caron, Captain of Artillery. An official report of the results has been published in the 'Annales des Mines' for 1862,[8] from which I present the following condensed account.

The difficulties to be encountered are chiefly two, the decarburization of the steel by oxidation, and the corrosion of the furnace by the oxide of iron generated. The first, it is alleged, has been overcome by covering the metal with a flux of common bottle-glass, or of blast-furnace cinder, and a remedy is suggested for the second. The conclusions at which the reporters arrived are succinctly given as under:

"1. That the fusion of the steel under this slag took place easily and rapidly without causing the metal to lose any of its qualities.

"2. That by this method of fusion, 2000 kil. (about 2 tons) of steel might be melted without difficulty in the same furnace.

"3. That actually, in spite of certain imperfections in the trial furnace, there would be notable economy, as well from the suppression of crucibles, as in the diminished consumption of the fuel employed in relation to the quantity of steel melted.

"4. That furnaces constructed of refractory bricks only offer an imperfect resistance (*ne résistent que médiocrement*) on account of the multitude of joints, and that it would be advantageous to make the beds and roofs either of one piece, or of a small number of pieces fitting together by grooved joints, like the beds of copper furnaces. [This construction of the beds of copper furnaces is new to me.]

"In fine, it seems well established, that the process of M. Sudre is a decided improvement in the fabrication of cast-steel, that it is susceptible of being used with advantage in practice, and that it will only further remain to make some experiments upon the nature of the materials most suitable to be employed in the construction of the furnace, and upon the forms best adapted to utilize all the heat of the furnace.

"We are convinced that it is every way to the interest of manufacturers to try the new process comparatively with the old one; and we doubt not that it will be eagerly adopted by our steel-makers, as soon as they learn the happy results of these first trials, made under the high patronage of the Emperor, trials which add a fresh testimony to the lively interest which inspires His Majesty concerning everything which may contribute to the progress of French industry."

Notwithstanding this wise generosity on the part of the Emperor, who defrayed the expenses of the investigation, we are informed that

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[8] 6ième série, 1. pp. 221-330.

Sudre's "processes are patented both in France and abroad, and cannot be employed without the consent of the inventor."

M. Sudre is not the first to employ bottle-glass as a flux in melting steel, for Huntsman is reported to have employed the same substance in his crucibles.*

I have not considered it worth while to present any detailed account of the experiments recorded in the paper to which the foregoing summary is prefixed. Numerous calculations as to the precise cost of melting steel in the reverberatory furnace compared with that of melting it in crucibles are given; but it will be time enough to consider this part of the subject when the process shall be adopted in practice, as it may possibly have been in certain establishments in Germany prior to the date of M. Sudre's patents. If the application of a reverberatory furnace, coupled with the use of bottle-glass, be properly the subject of a patent, it is not easy to divine what invention may not hereafter be patented.

The Addition of Manganese in the Casting of Steel.

In a patent granted in 1839, Josiah Marshall Heath[1] claimed the introduction of manganese,—as prepared by the reduction of a mixture of black oxide of manganese and carbonaceous matter at a very high temperature,—or, as it was termed, "carburet of manganese," into the crucibles along with the broken up blister steel to be melted into cast-steel.

The following is an extract from the specification, including all that relates to the carburet of manganese:

"I further propose to improve the quality of malleable or bar-iron by adding to the pig or plate-iron in the puddling-furnace, while in fusion, from one to five per cent., or thereabouts, of any pure oxide of manganese, but without mixture of any other substance, the sesquioxide being that which I prefer. Lastly, I propose to make an improved quality of cast-steel, by introducing into a crucible bars of common blistered-steel, broken as usual into fragments, or mixtures of cast malleable iron, or malleable iron and carbonaceous matters, along with from one to three per cent. of their weight of carburet of manganese, and exposing the crucible to the proper heat for melting the materials, which are, when fluid, to be poured into an ingot mould in the usual manner; but I do not claim the use of any such mixture of cast and malleable iron, or malleable iron and carbonaceous matter, as any part of my invention, but only the use of carburet of manganese in any process for the conversion of iron into cast-steel."

By this addition, blister-steel, prepared from the comparatively low priced bar-iron of British manufacture, will yield malleable, weldable cast-steel; whereas previously such cast-steel could only be made from high priced descriptions of bar-iron, such as the Swedish or

* The Useful Metals and their Alloys, p. 348.

[1] Improvements in the manufacture of iron and steel. A.D. 1839, April 5th. No. 8021.

Russian. Heath soon afterwards found that an intimate mixture of oxide of manganese and carbonaceous matter might be substituted for the so-called carburet of manganese, whereby the expense of the separate reduction of this substance might be avoided. He granted licences to certain steel-makers at Sheffield, and entered into arrangements to supply them with manganese in a suitable state for immediate application. Accordingly, instead of furnishing the identical substance, named in the specification, "carburet of manganese," he substituted the mixture above mentioned. A person, of the name of Unwin, was employed by Heath as an agent for conducting the commercial part of the business; and very soon this person started as cast-steel maker on his own account, using the mixture of manganese instead of the carburet, and denying that he had thereby infringed Heath's patent. Several steel-makers at Sheffield combined with Unwin, and provided a common fund, wherewith to contest Heath's claim to the application of the mixture. Costly and protracted litigation was the result, and the opponents of Heath finally triumphed over Heath's widow in an appeal to the House of Lords. One of the points repeatedly discussed before the Court was, whether carburet of manganese would necessarily be formed when the mixture was employed; for, if so, the use of this mixture would only be a colourable imitation, and would constitute an infringement of the patent. The scientific evidence was in favour of the production of carburet of manganese in the case of the mixture; and my conviction is, that this conclusion was perfectly justified. When a mixture of black oxide of manganese and an excess of carbonaceous matter is heated in close vessels so as to yield metallic manganese, the temperature must be extremely high; and it may be inferred, with a degree of certainty which would be regarded as conclusive by chemists in general, that in the presence of an excess of carbonaceous matter—a condition supposed—the metal would at the instant of its liberation take up carbon, and become what is designated carburet of manganese. The carburization of the metal would proceed *pari passu* with its reduction. Juries and some of the judges accepted this view; but other members of the bench came to an opposite conclusion. Not a few ridiculous remarks were made by some of these expounders of the law, as to the impossibility of looking into the crucibles heated to whiteness and seeing what goes on therein! The evidence in such a case cannot be actually demonstrative to the eye of an observer, yet may, nevertheless, be clear and decided.

My friend, Mr. Webster, who was one of the counsel for Heath, has published an excellent report of all the legal proceedings in this celebrated patent case, from which I have obtained my information on the subject.[2] The various judgments are given *in extenso;* and that of Lord Brougham especially should not be allowed to pass without comment in this work. His Lordship in the early part of his career devoted considerable attention to particular branches of science, especially

[2] The Case of Josiah Marshall Heath, the inventor and introducer of the manufacture of welding cast-steel from British iron. By Thomas Webster, M.A., F.R.S., Barrister-at-Law. London, 1856. pp. 115.

[illegible] to the following extract from Mr [illegible] report of the case:—

"Take the case [illegible] a patent [illegible] compound of what is now called sulphate of soda, which is a well-known compound of sulphuric acid, [illegible] and soda. Suppose a patent had been taken out for the use of glauber salts in the manufacture of any patent medicine, and suppose that, instead of using glauber salts, a person who was minded by a different process to arrive at the same kind of medicine had betaken himself to another process founded upon the fact of the composition of glauber salts being of that acid and that alkali, and suppose he had taken, I will not say an acid, though I might take the instance of an acid, but suppose he had invented his new patented drug as composed of soda and other materials which we may suppose to be analogous to the [illegible] in this case, and that the other material of his drug had been [illegible] or alcohol, or any other matter of that sort, and that he had exhibited to that sulphuric acid—in that case I should say that although sulphuric acid exhibited to the mixture of alcohol and soda would lead probably to the formation of vitriolic ether, sulphuric ether, in one respect, but would, there can be but little doubt, in another respect produce sulphate of soda, I do not think that that would have been an infringement of the patent. A very bad drug, in all probability, would be produced, and probably its use would give considerable confirmation to the jocose answer that was once made by a friend of ours at the bar to a medical man who complained that he had been engaged in law proceedings, and he said he did not find our profession made angels of men. 'Yes, but yours does,' said the learned counsel: 'that is the difference between our professions.' The one does not improve their character here, but the other, according to his idea, had a tendency to remove them from hence to another state of existence. Probably this drug, which I am supposing to be made, would very much tend to produce that effect.

"But I will now take another case. Supposing, instead of exhibiting sulphuric acid to soda and alcohol, and thereby getting glauber salts in one way or another, it had been an exhibition to alcohol of sulphuret of soda (*sic*), that is to say, a compound of sulphur and soda, and that that sulphuret of soda, with the alcohol, had been exposed to heat. I will suppose such a blast of hot air or the flame of a blowpipe driven upon the sulphuret of soda as should produce combustion of the sulphur, and consequently give rise to the formation of sulphuric acid and, the soda being present, of sulphate of soda. Can anybody say that would have been an infringement of the patent which was a patent for the exhibition of glauber salts, merely because, by the

elective attraction of the substances exhibited to one another, the combustion of the sulphur had given rise to sulphuric acid, and the sulphuric acid had united with the soda and produced sulphate of soda, which is equivalent to glauber salts? The answer to that would be, 'The patent is for glauber salts; we know what glauber salts are; we are told by this specification that the process is to exhibit glauber salts for making the medicine in question.' The party wishing to use the invention, and to infringe it, or to do what was alleged to be an infringement of it, would have said, 'No, I cannot use glauber salts, I know that well enough, because the specification claims the exclusive use of glauber salts. But I am not excluded from using sulphur, I am not excluded from using soda, I am not excluded from mixing sulphur and soda together with alcohol, and combining them with the oxygen of the atmosphere in order to get sulphuric acid, and thereby to make something of the same sort as the medicine in question: I am therefore free to do that, though I am not free to use glauber salts.'"

Whatever the decision of the law may be, the chemist would assert, that, in compounding physic, in which Glauber's salts or sulphate of soda is the essential constituent, it matters not whether the salt be directly employed, or the elements, sulphuric acid and soda, which, on coming in contact, would of necessity generate that salt; and that salt and not ether would, assuredly, be generated under the circumstances supposed by his Lordship. Even on the judgment-seat of the most dignified assembly in the world, his Lordship could not refrain from introducing a facetious anecdote. The retort of the barrister to the doctor was well timed; but his Lordship has omitted the rejoinder, which, doubtless, was made by the doctor, who added, "Angels of your profession! I hope so, but fear the reverse."

The illustration with respect to "sulphuret of *soda*" [sic] is positively absurd, and unworthy of serious comment. Another illustration, drawn from the manufacture of gunpowder, is presented by his Lordship, which, chemically regarded, is on a par with the last, and which I have not considered it worth while to introduce. Of the various judgments delivered in the course of these unparalleled proceedings, that of Lord Brougham is, undoubtedly, the least scientific and the worst expressed.

Evidence was advanced to invalidate Heath's patent on the ground of non-novelty.[3] The late Mr. Webster, of the Penns, near Birmingham, a man of high character, and well known as a manufacturer of piano-forte wire, deposed that he had, between the years 1827 and 1834, melted Swedish iron of inferior marks, cut into pieces, with black oxide of manganese and carbon. He had with his own hands weighed these materials, and put them into the melting-pot. The manganese was powdered, and the charcoal *in small pieces*. An im-

[3] A.D. 1799, Dec. 6, a patent (No. 2363) was granted to William Reynolds, for "Preparing iron for the conversion thereof into steel." The invention consists in the use of oxide of manganese, or manganese, in the conversion of pig-iron into malleable iron or steel, but neither proportions nor details are given. Abridgments, p. 17.

proved quality of steel was alleged to have been thus produced from inferior iron; and "the improvement was a greater degree of tenacity, and its [i.e. the steel] being perfectly malleable." The cast steel so made was called "malleable or welding steel." Mr. Webster used the greater proportion himself, and sold the rest as "malleable or welding steel." He bought regularly the quantity of manganese required from time to time. He further stated that "the making steel by black oxide of manganese and carbon has been in use from 1837 to the present time," and that he "was entirely ignorant of the patent of Heath till 1850." He had kept the process secret. Mr. Webster's evidence was, except as to the point of secrecy, corroborated by that of his son, now also deceased; but, on cross-examination, this witness declared that he had "given no instructions to keep it a secret," and that it was "a secret which every one knows." It will be observed that the charcoal, according to Mr. Webster, senior, was "in small pieces;" and from this, it is certain, that the reduction of the oxide of manganese must have been exceedingly incomplete.

Mr. David Francis Davis, manager of Messrs. Hunt (at the Brades' Steel-works, Tividale, near Birmingham), deposed that he had melted cast-steel at the Messrs. Hunt's works in conjunction either with oxide of manganese alone, or with that oxide and carbon. The product was called "welding cast-steel." He kept the process secret, and deceived the workmen, who were with him, when it was performed. Davis's evidence, as reported, is somewhat ambiguous. It is as follows:—"I made it [cast-steel]; I have made it with blistered steel and iron not converted; with iron I should put a large quantity of carbon; in both cases I should use carbon if needed [in the case of iron steel could not be made without it], and *have used oxide of manganese if I wanted it milder than usual;* the black oxide and the carbon reduced the temper: I have made it so soft that a blacksmith could not break it." The idea of carbon reducing the temper in the sense in which that expression is here used is ridiculous. It is perfectly clear that the "mildness" was the result of the oxidizing action of the oxide of manganese upon the carbon of the steel, whereby the latter became proportionately decarburized. The metal which was so soft that a blacksmith could not break it, closely approximated to malleable iron. In all the cases in which oxide of manganese was employed in the casting of steel before the publication of Heath's specification, it is probable that the effect produced was simply one of decarburization in a greater or less degree by oxidation, the oxygen being supplied by the oxide of manganese. But, in the manner in which Heath employed manganese, it is certain that it could not have occasioned any such result.

Evidence was advanced to the like effect by other witnesses, amongst whom was a Mr. Samuel Mitchell, who expressed the following dogmatic opinion:—"Carburet [of manganese] would not be formed before the steel was fused; it would be formed about an hour after steel was fused." The evidence on this point, it need hardly be observed, is worthless.

Witnesses, on the other hand, testified in decided terms in favour of the novelty of Heath's invention, especially Mr. Charles Atkinson, a manufacturer of steel at Sheffield for upwards of thirty years.

One thing seems undoubted, namely, that the use of carburet of manganese, or of a mixture of oxide of manganese and carbonaceous matter, did not come into use at Sheffield until after the publication of Heath's specification; and that is, assuredly, a strong argument in support of its claim to novelty. And to me it appears also clear, that those who professed to have previously employed oxide of manganese and carbon, could only have done so in a very inefficient manner, seeing that intimate admixture is absolutely essential to the success of the process, a condition to which they did not even make a passing allusion. Heath, on the contrary, prepared a *most intimate* mixture with coal-tar, which was afterwards dried, and hardened into lumps by heating it in close vessels. If the mixture be not intimate, rapid corrosion of the pots will be the result. Few persons, if any, have had more experience than myself in the production of metallic manganese or its alloys, so that I may be permitted to express myself somewhat decidedly on the subject. I have studied the report of Heath's case with great attention, and deeply reflected on the evidence; and the conclusion at which I have arrived is, that if any man ever deserved a patent, Heath was that man. Of course, I pretend to offer no opinion as to the law of the case, but judge simply according to my metallurgical knowledge, and the principles of what I believe to be common sense.

"A considerable degree of uncertainty," writes Mr. Webster, "is, unfortunately, an incident of the legal proceedings necessary for the maintenance and protection of property in inventions, but Heath's is a most remarkable instance of such uncertainty. The result of fifteen years' litigation—in which no less than *eighteen* learned Judges, Privy Councillors, and noble Lords took part—was that of eleven of the Judges, the Lord Brougham, and the Lord Chancellor—*seven* were in favour of and *six* against the claim of Mr. Heath; of the *eleven* Judges who delivered their opinions to the House of Lords, at the final stage of the proceedings, *seven* were in favour of, and *four* against, the claim of Mr. Heath; and the House of Lords decided in conformity with the opinion of the minority."

Mr. Webster puts the issue clearly in few words, as follows:—"Mr. Heath was the author of an invention conferring commercial profits to be reckoned by millions; he described the invention in one set of terms, according to the best of his knowledge at the time. The manufacturers adopted a process chemically equivalent, the same in effect and result, but admitting of being described in somewhat different terms, inasmuch as it consisted in the use of the known chemical elements of the substance [and which, Mr. Webster might have added, must of necessity have produced that substance under the conditions of its application], instead of the substance itself. The knowledge of the use of these elements instead of the substance was communicated by Mr. Heath to the manufacturers, within a few months

after the date of his patent, and while the invention, so to speak, was on its trial [illegible] by the manufacturers. [illegible] under the advice and direction of Mr. Heath and his agent [illegible] in the first experiments, and [illegible] a saving of [illegible] on the cost of the steel. The royalty demanded by Mr. Heath was [illegible]. The payment of this or of any sum to Mr. Heath was refused by a section of the steel-manufacturers, who [illegible] in the [illegible] to [illegible] a common fund wherewith to [illegible] his [illegible]. The [illegible] of the fifteen years [illegible] against a common purse, the accumulation of the wealth which he had created."

According to Mr. [illegible], Heath's is the only reported case in which the [illegible] of a [illegible] has been overruled by the [illegible]. Heath was in the Honourable East India Company's civil service in the Madras District, and it was he who established the Porto Novo Iron-works. He died in the interval between the [illegible] in [illegible] and the subsequent proceedings in the Exchequer Chamber in [illegible]. His death, there is good reason to believe, was hastened by the anxiety and difficulties in which he became involved in attempting to maintain his rights. Of all the actors in this "eventful drama," as Mr. [illegible] properly designates it, the agent [illegible] is [illegible] to be admired or envied.

The [illegible] of the action of manganese upon cast-steel.—It might have been expected that this action would long ago have been clearly ascertained; but, so far as I know, this, unfortunately, is not the case. It can only be determined by accurate chemical analysis. Steel is manufactured which, if melted per se, can neither be worked satisfactorily under the hammer, nor welded, but becomes both malleable and weldable by fusion with a small proportion of manganese. The [illegible] which the manganese may [illegible] cannot, [illegible], be concerned in this action, which must be [illegible] due to the metal itself. Is the action mechanical, or chemical, or both?

At my request, Mr. E. F. Sanderson prepared for me specimens of cast-steel made from the same bar-steel melted without and with manganese in the manner usually practised in Sheffield. They were in the form of ingots, showing fracture, and were accompanied with specimens of the same steels tilted to a smaller size. Analyses of portions of the ingots have been made in my laboratory by Mr. A. Dick, the carbon alone not having been determined. The results are as follows:—

	I.	II.
	[illegible]	Melted with manganese.
Iron	[illegible]	[illegible]
Manganese	[illegible]	[illegible]
Silicon	[illegible]	[illegible]
Sulphur	[illegible]	[illegible]
Phosphorus	[illegible]	[illegible]
Arsenic	[illegible]	[illegible]
Carbon not determined	—	—
	[illegible]	[illegible]

Traces of lead, tin, and copper were found in No. II. by operating upon 1200 grains; but no similar examination was made of No. I. The analyses were made with the utmost care, and the reagents employed were specially tested as to purity. Both steels perfectly dissolved in hydrochloric acid, without any trace of residue. Not a trace either of lime or magnesia could be detected.

The effect of fusion with manganese appears to have chiefly consisted in removing 0·11 % of aluminium, and adding 0·07 % of manganese. But it must not be supposed that I presume to draw any decided general conclusion from two analyses only. I present them because the results may be useful to others, who may be induced to investigate this interesting subject in a proper manner.

The late Mr. T. H. Henry entertained the opinion, that a certain proportion of silicon was essential to good steel, and was as important as carbon. In a communication to Mr. E. F. Sanderson concerning the action of manganese, he thus expressed himself:—"The manganese which you use, if it be such as I have seen, is a carburet of the metal, containing a considerable quantity of silicon; and it must not be forgotten that you introduce these substances into your steel by fusing them together. Now, there is no doubt that the steel becomes more fusible, more uniform and homogeneous in its texture by this addition. I do not, however, believe that this is owing to the metal, manganese, which is alloyed with the iron, but to the compound that you add. It is a flux at a high temperature, which unites with the steel; and, although it may improve its smoothness and uniformity of composition, so to speak, yet I have no doubt that it must affect its elasticity in some degree." Mr. Henry lays particular stress on the comparatively large proportion of silicon, which he found in hoop L iron. The influence of silicon on steel has not been sufficiently investigated to justify a decided conclusion on the subject; and the correctness of Mr. Henry's opinion can only be determined by accurate experiments.

Mr. Parry has recently investigated the properties of steel alloyed with manganese; and the conclusions at which he has arrived are, that it is a corrective of red-shortness, so that cast-steel, which can only be hammered or rolled at a low red-heat, may, when alloyed with from 0·5 % to 1·0 % of manganese, be hammered or rolled at a much higher, and even welding, temperature; but that the presence of manganese in sensible quantity in steel renders it more brittle while cold. Mr. Parry, therefore, suggests that it is desirable to avoid having recourse to manganese, and that, in order to this, it will be necessary to employ more powerful machinery for rolling than is now generally in operation. This suggestion deserves careful consideration, especially at the present time, when so much attention is being directed to the production of steel on the large scale for purposes of construction.

Hardening and Tempering Steel.

When steel is heated to redness, and then plunged while red-hot into cold water, or is otherwise suddenly cooled, it acquires great

hardness and brittleness. On reheating to redness and allowing it to cool slowly, its original softness and malleability are restored; and when it is reheated even far below redness, and afterwards suddenly cooled, it is also softened, the degree of softening, within certain limits of temperature, being inversely proportionate to the temperature. It is thus possible to communicate to the same steel widely different degrees of hardness; and the process by which this is effected is called tempering. The steel is first rendered extremely hard in the manner above stated, and is subsequently reheated and suddenly cooled at different temperatures according to the degree of hardness, or the "temper," desired. During the process of reheating, the surface of the steel having been previously brightened, will present a succession of characteristic colours corresponding to different temperatures; and, consequently, these colours render the use of thermometrical instruments unnecessary. In the following table these colours are stated in the order of their appearance, with the accompanying temperatures:[4]—

Temperature. Centigrade.	Temperature. Fahrenheit.	Colour.	Temper of various articles.
221°	430°	Very pale yellowish	Lancets.
232	450	Pale straw	Best razors and most surgical instruments.
243	470	Full yellow	Common razors, penknives, etc.
254	490	Brown..................	Small shears, scissars, cold chisels for cutting iron *cold*, hoes.
265	510	Brown dappled with purple spots	Axes, plane-irons, pocket-knives.
277	530	Purple	Table-knives, large shears.
288	550	Bright blue...........	Swords, watch-springs, bell-springs.
293	560	Full blue	Fine saws, daggers, augers.
316	600	Dark blue	Hand and pit saws.

It has long been known that by hardening steel expands sensibly, and consequently decreases in specific gravity. Reaumur seems first to have recorded the results of accurate experiments on the subject: "M. Perrault," he writes, "has already observed before us that a steel wire after hardening could not pass through the same hole as before hardening; I have repeated this experiment in many different ways, and I have always found an increase of volume in hardened steel; but I wished further to ascertain the extent of this increase, and whether it was sufficient to admit of being determined by measurement. I had made callipers of iron, in which a piece of steel, 6 in. long, just fitted; my pieces of steel were usually 2 in. wide by 6 lines thick. After they had, in the process of hardening, acquired a whitish red colour, I always found them at the least 1 line longer than in the original soft state: there was increase in other directions, as well as length, but this it was not so easy to measure as elongation; that is no reason for doubting that it was proportionate to the increase in length.

[4] Parkes's Chemical Essays. 4. p. 465.

This granted, the diameters of the volumes of steels hardened at a certain degree of heat, are to those of the volumes of steels not hardened, at least as 145 to 144." Hence, Reaumur computed that in the process of hardening steel increased $\frac{1}{48}$ in volume.[5] Rinmann states that he confirmed the truth of the preceding observations of Reaumur: he found that two pieces of cement or blister-steel (*Brennstahl*) had the specific gravities 7·751 and 7·991 in the unhardened state; and after hardening the respective specific gravities 7·553 and 7·708.[6] The same metallurgist remarks that the specific gravity of Styrian steel, on the contrary, is 7·782 in the unhardened, and 7·822 in the hardened state, and that by hardening it is reduced $\frac{1}{37}$ in volume.[7]

The amount of change in the volume of steel induced by hardening will vary with the temperature at which it is heated previously to cooling. When steel is hardened at a very high temperature, it loses all tenacity and elasticity, and becomes extremely brittle; and these effects are ascribed by Karsten to the greater increase of its volume consequent on such treatment.[8]

Elsner has determined the effect of hardening upon the specific gravity of cast-steel.[9] The results are as under:

	Specific gravity at 11° C. Unhardened.	Hardened.
Cast-steel	7·9288	7·6578
Ditto remelted	8·0923	7·7647
The same cast-steel melted with $\frac{1}{300}$ of silver	8·0227	7·9024

Caron has recently published several observations on the exact changes in dimensions which steel undergoes in hardening.[1] A bar of steel of superior quality heated to the requisite temperature to harden well, and immediately plunged into cold water, suffered the following changes in dimensions:

	Before.	At a red heat.	After hardening.
Dimensions in centimetres	20·00	20·32	19·95
	1·00	1·03	1·01
	1·00	1·03	1·01
Volume in centimetres ...	20·00	21·557	20·351

A bar of hammered steel 1 centimetre square by 20 centimetres long, after hardening, decreased 0^{m}005, and the other dimensions increased 0^{m}006. As these differences were very small, Caron repeated the operation of hardening several times upon the same piece of steel, and obtained the following numbers:

	Before hardening.	After hardening 10 times.	20 times.	30 times.
Dimensions in centimetres...	20·00	19·50	18·64	17·97
	0·94	0·96	0·97	1·00
	0·93	0·96	0·97	1·00
Specific gravity	7·817	—	—	7·743

These experiments were repeated upon a great number of bars of steel of good quality, and always with similar results, the bars decreas-

[5] L'Art de convertir le Fer forgé en Acier, 1722. p. 313.
[6] Geschichte des Eisens. 1785. 1. p. 134.
[7] Ibid. p. 137.
[8] Karsten, Eisenhüttenkunde. 4. p. 529.
[9] Journ. für praktische Chemie. 1840. 20. p. 110.
[1] Comptes Rendus. 1863. 56. p. 211.

[illegible]

	Before hardening.	After hardening.
[illegible]	[illegible]	[illegible]

[illegible] degree of [illegible].[2]

The following results were [illegible] with the same bar of steel heated and [illegible] with different degrees of [illegible].

	[illegible]	[illegible]	[illegible]	[illegible]
Temperature [illegible] of the liquid [illegible] hardening	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] after hardening	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] of the [illegible] of the metal	[illegible]	11.3	[illegible]	21.7
Quality of the hardening	good	feeble	very feeble	none
Diminution in the length of the bar after hardening ten times	[illegible]	[illegible]	[illegible]	insensible

From a great number of experiments on hardening steel in different liquids, such as mercury, water charged with different salts or acids, water covered with oil or containing in solution mucilaginous or syrupy matters, oil, etc., Caron concludes that the hardness and other effects produced by hardening appear always to be inversely proportionate to the square of the time of cooling of the metal, which depends on the temperature, the specific gravity, the specific heat, the conductivity, and "perhaps also on the mobility of the liquid employed in hardening."[3]

When hardened steel is reheated to redness, and afterwards left slowly to cool, it acquires its original specific gravity, or what is equivalent, its original volume.[4]

The scale of oxide of iron, with which steel becomes coated when heated to the welding point with access of atmospheric air, is detached completely by plunging the metal while nearly white-hot into cold water, leaving a clean, smooth, silver-white metallic surface. This, it is alleged, is owing to the different rate of contraction between the

[2] Useful Metals and their Alloys. p. 369. [3] Op. cit. p. 215.
[4] Karsten, Eisenhüttenkunde. 4. p. 526.

scale and the metal;[5] but, possibly, the particular nature of the surface of steel may also tend to prevent adhesion of the scale. If the steel is heated to redness, and then cooled in cold water, the surface will not be uniformly metallic, but more or less mottled with a dark skin of oxide.

Hardening and tempering sensibly modify the fracture characteristic of steel, especially after tilting, *i. e.* drawing out by quickly repeated blows of the hammer. When a small tilted bar of cast-steel, of which the fractured surface to the unaided sight presents no distinct appearance of grain, is heated to redness, the fracture becomes distinctly granular; and this occurs whether the metal is plunged while red-hot into cold water, or is left slowly to cool. The size of the grain, *cæteris paribus*, increases with the temperature to which the metal is exposed before hardening. Hardened at a cherry red-heat in cold water, steel may present a more or less velvety dull fracture, of which the grain is so fine as to be no longer visible to the naked eye. The fracture becomes brighter and lighter in colour by hardening. The appearances above described can only be seen in a satisfactory manner on the fractured surfaces of small tilted bars, especially of cast-steel. Schafhäutl has described with great minuteness the appearances, with and without the aid of the microscope, of the fractured surfaces of steel produced after hardening at different temperatures; and he states that the fracture of a thin tilted bar of steel, after hardening at a cherry red-heat in cold water, resembles the surface of the moon as seen through a good telescope![6]

By hardening, within certain limits of temperature, the tenacity of steel is increased; but beyond those limits, which may be stated as bright redness and the welding-point of the metal, the reverse is the fact. If hardening is effected at or near the welding-point, the fracture becomes coarse-grained, and the steel is said to be "burnt." For each variety of steel there is a particular temperature, at which, after cooling in cold water, the maximum tenacity is produced; but this maximum is not always desired, as in many cases it is necessary to sacrifice tenacity in order to obtain proportionately greater hardness. It has been propounded that steel which acquires its maximum tenacity combined with sufficient hardness by hardening at the lowest temperature is to be regarded as the best. General propositions of this kind are unsatisfactory. Steel, which may be best for one purpose, may be worst for another; and there is no steel which is equally suited for all purposes. When, consequently, the terms good and bad are applied to steel, they should be used with reference to the special objects for which the metal is intended. However, it must not be inferred from these remarks, that there is no *absolutely* bad steel; for metal, miscalled steel, has often been made which is quite unfit for any purpose whatever. A minute difference in the composition of steel may cause a striking alteration in its quality; and it is certain that the numerous varieties of steel in commerce do differ sensibly in compo-

[5] Karsten, Ibid. p. 526. [6] Technologische Encyklopädie, Prechtl. 15. p. 334.

sition. There are five elements especially, namely carbon, silicon, sulphur, phosphorus, and manganese,—and there are probably others,—which, in minute proportion, are known to affect the quality of the metal; and as the proportions of these substances vary sensibly in different kinds of steel, the reason of the great diversity in steels is readily intelligible. These differences in composition depend chiefly on corresponding differences in the composition of the malleable iron or the pig-iron, from which the steel has been derived. Le Play speaks of the "steely propensity" (*propension aciéreuse*[7]) of certain descriptions of iron, which is simply an expression of ignorance, and nothing less. Now, it is only by careful observations during long experience that workmen engaged in the hardening and tempering of steel can acquire the knowledge requisite to enable them to determine correctly the temperatures best adapted for hardening the particular varieties of steel in commerce; and this, not with the aid of thermometric instruments, but by the education of the eye alone.

As has been previously stated, the physical properties of steel depend not merely upon the causes above assigned, but also upon the temperature and rapidity with which, in tempering, cooling is effected. Thus, if two bars of the same steel be hardened at the same temperature, cooled in the same water, reheated under the same conditions until they exhibit the same superficial colouration, and then cooled, one in water and the other in oil at the same temperature, each will receive a different temper owing to the different rates of cooling in the water and oil respectively; differences depending on the different conductivity for heat, the different capacity for heat, and as Caron suggests, probably also on the different mobility of the two liquids. Hence, even in ancient times, much importance has always been ascribed to the liquids employed in tempering; and now-a-days some workers in steel affect considerable mystery in this respect. In the days of Pliny, it was maintained that the quality of the steel mainly depended on the nature of the water used in the process of hardening; and in proof of this, he cites several localities, celebrated on account of their steel-works, which had been erected solely in consequence of the supply of suitable water, as no iron ores existed in those localities.[8] The effects referred to these waters were, no doubt, greatly overrated; yet the belief in their efficacy had some foundation in the fact that the conductivity of water for heat may be modified by the presence of saline matters in solution. Of all liquids mercury will effect the most rapid cooling, on account of its superior conducting power, as compared with water and other liquids; and for experimental purposes, it may be conveniently employed. But on the large scale its use may be dangerous to the workmen, unless extraordinary precautions be observed to prevent contact with it or the escape of its vapour; and while these would probably be attended with difficulty, they might not after all be perfectly efficacious. Tempering at higher

[7] Annales des Mines. 4 s. 3. p. 608.

[8] Lib. xxxiv. cap. xiv. sect. 41. Sillig's edition. 1851. 5. p. 185. "Summa autem differentia in aqua cui subinde candens inmergitur."

temperatures than is possible in water may be effected in saline solutions, in oil, and in metallic baths of easily fusible alloys. The use of oil for this purpose is mentioned by Pliny, as applicable to varieties of the metal which would become too hard by immersion in water;[9] and it has ever since been similarly employed. Yet, only a few months ago, it was put forth in the newspapers that Mr. Anderson, of the Arsenal, Woolwich, had made a wonderful discovery in tempering in oil the breech-pieces of Sir William Armstrong's guns. No one, I should suppose, would be so much surprised or annoyed as Mr. Anderson himself, at being thus announced as the inventor of a process in operation ever since the days of Pliny.

In hardening and tempering, two of the most important conditions to be sought are, that the steel in hardening should be heated and cooled as uniformly as possible throughout, and that in tempering it should also be heated and cooled as uniformly as possible throughout. With small objects these conditions are not difficult to be attained; but in large objects, it is obvious that the reverse must be the case. It is possible that in the heating of such objects, every particle of the metal may be raised to the same temperature; but in the processes of cooling, it is not possible that every particle should be cooled at the same rate, for the central portion will necessarily be more slowly cooled than the exterior.

It is beyond the province of this treatise to describe the numerous minute details of manipulation in the tempering of objects of steel of different forms and dimensions, and of different qualities according to the purposes for which they are designed. A little work on this subject has recently been published by an experienced manipulator in steel, Mr. Ede, of the Royal Arsenal, which, so far as I am able to judge, appears to contain much valuable information for the guidance of those who intend to devote themselves to what was formerly designated "the mystery of tempering steel."[1] I, for one, am very thankful to men practised in any of the Metallurgic Arts, who will come forward and inform us in an unpretending manner what they know about their own particular craft. Mr. Ede has done this, and deserves the thanks of the public for his pains.

When the steel is what is termed "good," the temperature, at which it is hardened, should not exceed low redness; and it is recommended that the water in which it is immersed should not be quite cold, but "have the chill off." Objects having a bright metallic surface are stated to be more liable to crack in hardening than the same objects "with the skin on," *i. e.* having the surface coated with a film of oxide of iron, which it acquires in rolling or hammering. When an article consists of a thick and a thin part, the former should be first immersed

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[9] Pliny, lib. xxxiv. cap. xiv. sect. 41. p. 186. "Tenuiora ferramenta oleo restingui mos est, ne aqua in fragilitatem durentur."

[1] The Management of Steel, including Forging, Hardening, Annealing, Shrinking, and Expansion; also the Case-Hardening of Iron. By George Ede, employed at the Royal Gun Factories Department, Woolwich Arsenal. 2nd ed. London. 1863. Small 8vo., pp. 31.

in the water, in order, as far as practicable, to equalize the rate of cooling through the mass. This, however, cannot always be done, as some articles are thickest in the centre; and these should be gradually immersed perpendicularly, moved up and down in, but not raised above, the water. In hardening and tempering articles such as eccentric collars, a piece of iron may be first fitted on the thin side, so as to make it equal in thickness to the thick side, whereby the rate of heating and cooling is more or less equalized in every part. It is asserted that if large pieces of steel are taken out of the water before having become quite cold, they are very liable to crack. Mr. Ede lays particular stress on this point, and declares that "hundreds of things break by lifting them out before they are cold." The same practical writer states, that he has had much experience in the use of a bath of red-hot lead for heating preparatory to hardening; and that, although he has found it to answer admirably for many articles, yet he always avoids having recourse to it except in cases of necessity, because he has experienced ill effects from the action of the metal heated to this temperature. Before immersing the articles in lead, they should be rubbed over with soft soap, a mixture of black lead and water, or plumber's size. Except when soft soap is employed, the articles should be well dried before immersion in the lead.

In tempering, various obvious expedients are adopted in order to heat the article with uniformity, such as heated cast-iron plates, sand-baths, oil or tallow-baths, metallic baths, etc. The following table, showing the melting points of various alloys of lead and tin, was published by Parkes many years ago for the use of working cutlers.[2]

A NEW TABLE OF THE COMPOSITION OF METALLIC BATHS FOR THE USE OF WORKING CUTLERS.

No.		Composition of the bath. Lead.	Tin.	Temperature Fahrenheit.
1	Lancets	7	4	420°
2	Other surgical instruments	7½	4	430
3	Razors, etc.	8	4	442
4	Penknives and some implements of surgery	8½	4	450
5	Larger penknives, scalpels, etc.	10	4	470
6	Scissors, shears, garden hoes, cold chisels, etc.	14	4	490
7	Axes, firmer chisels, plane irons, pocket knives, etc.	19	4	509
8	Table knives, large shears, etc.	30	4	530
9	Swords, watch springs, etc.	48	4	550
10	Large springs, daggers, augers, small fine saws, etc.	50	2	558
11	Pit saws, hand saws, and some particular springs...	Boiling linseed oil		600
12	Articles which require to be still somewhat softer...	Melting lead		612

In 1854, a patent was granted to James Horsfall, of Birmingham, for a process of tempering steel wires for pianofortes and other musical

[2] Chemical Essays, 1815. 5. p. 269.

instruments.[3] This patent, which has, I understand, proved highly lucrative, deserves particular notice, especially as a patent subsequently obtained by another person was considered to be an infringement, and led to the usual expensive litigation. The descriptive part of the specification is as follows:—"After the wire has been drawn by the usual process to nearly the diameter which it is intended the finished wire shall have, I subject the said wire to the following treatment: I heat the said wire to redness, and immerse it when so heated in water or oil; by this treatment the wire is made hard. I afterwards plunge the said hardened wire into a bath of melted lead, or other bath having about the temperature of the melting point of lead; I allow the said wire to remain in the said bath until it has acquired the desired temper. The length of time will vary with the size of the wire. After this hardening and tempering process the wire is submitted to a final drawing, by which it is reduced to the proper size. Although I have described the method of hardening and tempering, which I have found in practice to answer very well, yet I do not limit myself thereto, as other methods of hardening and tempering may be resorted to; and although I prefer to harden and temper the wire immediately before the final drawing, as herein described, yet the said hardening and tempering may be effected at any stage of the drawing process prior to the final drawing. By the treatment described, the wire acquires a hardness and tenacity, which admirably fit it for pianofortes and other musical instruments.

"I claim as my Invention hardening and tempering steel wire for pianofortes and other musical instruments previous to the final drawing, by which the wire is reduced to the proper diameter, as herein described."

The essence of this patent consists in finally drawing the wire tempered at about dark blue, *i. e.* about the melting point of lead. Experience, I am informed, has amply confirmed the practical value of this very simple invention.

The other patent, to which I have referred, was granted to William Smith, of Aston, near Birmingham, in 1856.[4] The essential part of the process is described in the following extract from the specification: "My improvements in the manufacture of such wire relate to the processes of annealing the steel, and they have for their object a rapid and uniform heating of it to redness when in a mass, whether such mass consist of a considerable length of steel wire coiled together, or in any of the previous stages, to the solid bar, and submitting such masses of steel, when heated to the extent desired, to the action of manganese. And the improvements consist in so arranging the parts of the annealing furnace that the fire is prevented acting directly upon the steel, whereby the outer surface thereof would be subject to injuries from the intense heat thereto, and the heat is obtained by radiation.

[3] An Improvement or Improvements in the Manufacture of Wire for Pianofortes, and other Musical Instruments. A.D. 1854, May 15th. No. 1104.

[4] Improvements in the Manufacture of Steel Wire for Musical and other Purposes. A.D. 1856, April 15th. No. 897.

"The part of the furnace which receives the steel, in wire or other form, is separated on the one side in part from the fire-place (which is in the same arch or chamber) by a wall rising towards the roof or arch of the furnace, and on the other side by a similar wall from the escape to the flue, by which the current of heated matter will be caused to pass over the masses of steel on the furnace bed, and only heat the same by radiation.

"I do not, however, confine myself to the precise arrangement of furnace explained, as variations may be made therein; and I find that by such arrangement of annealing furnace the heat will communicate very rapidly throughout the entire mass of metal under operation; and when heated to the extent desired, which usually occupies from six to ten minutes, the mass is to be immediately plunged into oxide of manganese, and it then goes through the usual process of drawing to reduce it to the size required without further annealing. . . . . What I do claim is, the heating of steel used in the production of wire for musical and other purposes, for the purpose of annealing in furnaces of the character described, and then subjecting such steel thus heated to the action of oxide of manganese."

The essence of this patent seems also to consist in finally drawing the wire after it has been hardened to a certain degree, though the mode of tempering differs from that described in the specification of the former patent. The question is whether plunging the heated wire in oxide of manganese is simply a mode of tempering the wire to the degree specified in Horsfall's patent, or whether the oxide of manganese would act specifically and in a manner different from brick-dust, oxide of iron, lime, etc. An action for infringement was brought by Horsfall against Smith. Chemical witnesses, as usual, were summoned to state their opinions, etc., and the result was a verdict for the defendant.

Theory of hardening and tempering steel.—In a former part of this volume, under the head of Compounds of Iron and Carbon, several facts are recorded which tend to elucidate this curious subject. The questions which naturally first suggest themselves are, whether the physical difference between hard and soft steel depends simply on a physical cause, or whether it is due to chemical change, or whether it depends upon both these causes?

Now, it appears to be established, that a piece of steel, which, when hardened, dissolves completely in hydrochloric acid, always yields a sensible amount of carbonaceous residue when subjected in the soft state to the action of the same solvent. Mr. Faraday, so far as I have been able to ascertain, first pointed out this difference in 1822.[*] "The powder," he writes, "procured from the soft steel or alloy in these experiments, when it has not remained long in the acid, exactly resembles finely divided plumbago, and appears to be a carburet of iron, and probably of the alloying metal also [*i.e.*, alluding especially to steel alloyed with platinum]. It is not acted upon by water, but in

[*] On the Alloys of Steel. Phil. Trans. Read March 21, 1822, p. 265.

the air the iron oxidates and discolours the substance. When it remains long in the acid, or is boiled in it, it is reduced to the same state as the powder from the hard steel or alloy. When any of these residua are boiled in diluted sulphuric or muriatic acid, protoxide of iron is dissolved, and a black powder remains unalterable by the farther action of the acid; it is apparently in greater quantity from the alloys than from pure steel, and when washed, dried, and heated to 300° or 400° [F.] in the air, burns like pyrophorus with much fume; or if lighted, burns like bitumen, and with a bright flame; the residuum is protoxide of iron and the alloying metal. Hence, during the action of the acid on the steel, a portion of hydrogen enters into combination with part of the metal and the charcoal, and forms an inflammable compound not acted upon by the acid. Some striking effects are produced by the action of nitric acid on these powders. If that from pure steel be taken, it is entirely dissolved; and such is also the case if the powder be taken from an alloy, the metal of which is soluble in nitric acid; but if the powder is from an alloy, the metal of which is not soluble in nitric acid, then a black residuum is left not touched by the acid, and which, when washed and carefully dried, is found, when heated, to be deflagrating; and with some of the metals, when carefully prepared, strongly explosive."

Hardened steel is much less readily acted upon by acids than the same steel softened; and in proof of this, the following experiment by Daniell may be cited. "A bar of steel of an even granular fracture was broken into two. The two pieces were heated in a furnace to a cherry red. In this state one of them was plunged into cold water, and the other allowed very gradually to cool by the slow extinction of the fire. They were both placed in muriatic acid, to which a few drops of nitric acid had been added. The last was gradually attacked, but it required fivefold as much time to effect the saturation of the acid of the first. When the solvents had ceased to act they were both examined. The tempered [hardened] steel was exceedingly brittle, its surface was covered with small cavities like worm-eaten wood, but its texture was very compact and not at all striated. The untempered [softened] steel was easily bent and not elastic, and it presented a fibrous and wavy texture."[6]

In molten, or even in strongly heated solid, steel, the carbon is wholly combined, or, possibly, simply dissolved; and by sudden solidification of the metal in the one case, or sudden cooling of it in the other, the whole of the carbon remains diffused through the mass. However, the carbon may have separated notwithstanding, and exist in a state of infinitesimally fine division; and it is conceivable that it may be in the allotropic condition of graphite, and may yet, owing to what I will venture to designate an atomic state of disaggregation, be capable of entering into combination with nascent hydrogen, and produce the residue supposed to be indicative of the presence of what is termed *combined* carbon. Whether this view be

[6] The Journal of Science and the Arts. 1817. 2. p. 281.

correct or not, it is certain that hard and soft steel differ essentially with regard to the mode of existence of the carbon in the mass.

The presence of carbon, or some other element, is essential in iron to enable it to harden when heated to redness and suddenly cooled; and, as far as I am aware, no pure metal is sensibly affected in its physical properties by this process. Certain alloys, it is well known, do suffer a change in physical properties by sudden cooling; and several examples of such change have been recorded in the First Part of this work. Thus the alloy of copper and tin, termed bronze, is softened by plunging it while red hot into water; and an alloy of zinc, with a small proportion of lead, is hardened by rapid solidification after fusion.

The particles of hardened steel are obviously in a state of tension, which may, probably, be analogous to the particles of glass in the unannealed state; and if the former were transparent, the polariscope would, it is reasonable to suppose, reveal a structure similar to that which it renders manifest in the latter.

HAMMERING STEEL.

By properly hammering steel at suitable temperatures, the structure, or, as it is frequently termed, the texture of the metal is remarkably affected, and its tenacity, moreover, may be greatly increased. The effect of hammering is to produce fineness of grain, as manifest on the fractured surface; and if the fracture of a small hammered—or, to use the technical expression, tilted—bar of steel be compared with that of a portion of the same bar heated to redness and afterwards slowly cooled, a striking difference will be observed, the grain being much larger in the last. The temperature at which steel may be hammered depends upon its quality, or, in other words, upon its chemical composition. Some varieties can only be hammered without cracking at very low temperatures, comparatively, and, consequently, entail considerable expense in forging, as the facility with which a metal may be fashioned under the hammer will vary directly with its softness, and its softness will, *cæteris paribus*, be proportionate to its temperature. Wootz, for example, can only be worked at a very low red heat. On the other hand, there are steels which may be hammered or rolled at very high temperatures, comparatively.

WELDING STEEL.

The facility with which steel may be welded to steel diminishes as the metal approximates to cast iron with respect to the proportion of carbon; or, what is equivalent, it increases as the metal approximates to wrought iron with respect to absence of carbon. Hence, in welding together two pieces of steel, *cæteris paribus*, the more nearly their melting points coincide,—and these are determined by the amount of the carbon which they contain,—the less should be the difficulty. If the melting points sensibly differ, then the welding point of one may be near the melting point of the other; and the

difference in the degree of plasticity, so to speak, between the two pieces may be so considerable, that when they are brought under the hammer at the welding point of the least fusible, the blow will produce a greater effect upon the latter, and any inequality in this respect must be disadvantageous. This constitutes the difficulty in welding steel to wrought iron. Moreover, a difference in the rate of expansion between any two pieces of metal to be welded together is another obviously unfavourable condition.

Shear Steel.

Bars of blister-steel are broken into pieces about 16 in. long, and drawn out at a red heat under the hammer to the width of about 1½ in. and the thickness of about ½ in. Several bars thus obtained are piled on one another, and the end of the pile is firmly wedged into an iron hoop with a handle attached to it. The free end of the pile is raised to a welding heat in a hollow coke fire, during the process being dusted over with finely-pounded clay, welded under the hammer, and reduced to about 2 in. square. The hoop is now detached from the other end of the bar, and this end is treated in exactly the same manner as the first end. In this state it is termed "single shear-steel." It may be broken into two equal parts, which may again be welded together and drawn out to any required dimensions to form "double shear-steel." The dusting with clay is intended to prevent superficial oxidation and consequent decarburization as far as practicable. The word shear was originally applied from the fact that the blades of shears, formerly used for cropping woollen cloths, were always made as above described.[7]

Casting Steel on Wrought Iron.

Of late it has been found practicable to effect a very intimate union between wrought iron and steel by bringing the latter in a molten state in contact with the former, previously raised to a white heat, and having its surface dusted over with borax in order to render the scale extremely fusible. In the International Exhibition, 1862, were rail tyres, consisting of wrought iron, around which externally cast steel had been poured. I examined these tyres, both whole and fractured, and the union between the two rings of metal seemed to be perfect. I also examined a portion of one of these tyres, which had been hammered out hot on one side to an edge, and yet I detected no sign of separation. This invention is French, and the tyres are manufactured in England by the Monkbridge Iron Company, near Leeds. The following description of the mode of manufacture is extracted from a printed circular issued by that firm:—" The inner part or back of the tyre is of the best Yorkshire iron, specially suitable for the purpose, and the outer surface or tread and flange is of refined cast steel. The iron which is to form the inside of part of the tyre is hammered and rolled into a perfect solid ring of the size required, and this is

[7] Vid. The Useful Metals and their Alloys, p. 345.

placed, when at a welding heat, into the ingot mould, the surface being carefully deoxidized,[8] and the molten steel is poured on the iron, into the space between the ring and the inner face of the mould. The iron being at a welding heat, and the steel at a still higher temperature, a perfect weld is thus ensured. The ingot is then taken and subjected to a hammering process in its circular form, to give it that solidity and uniformity which can only be ensured by hammering, and is afterwards rolled to the exact size and shape required, upon a powerful rolling machine constructed specially for the purpose. The tyre is finished so exact and circular that it is ready at once to be put upon the wheel, without being turned on the outer surface—a point of great importance, as the outer skin is always the hardest and most uniform part of the tyre. The union of the steel and iron thus formed is so complete and perfect, that it is impossible to separate them; and in every case where they have been broken for the purpose, it has been found that they cannot be disunited either by punching or in any other manner."

Damaskeening.

The meaning and origin of this word have been explained in an early part of this volume, and it has been several times referred to when treating of the alloys of iron. Damascus was long celebrated for the manufacture of its sword-blades, which, it has been conjectured, were made from the wootz of India.[9] These blades, after having been polished, are subjected to the action of acid or other corrosive matter; a peculiar pattern or watering soon appears upon their surface, due to inequality of some kind in the metal, and the consequent irregularity in the action of the acid. It is only within the present century that the cause of this inequality has been clearly understood, and the method of manufacture explained. The damasked pattern is due to the difference in colouration resulting from the action of acids on iron and steel, the surface of the former being left with a metallic lustre, and that of the latter being left coated with a black, firmly adherent carbonaceous residue. By suitably piling together bars of steel and iron, welding them, and then drawing them out under the hammer or otherwise, patterns of various kinds may be produced, just as is done in the case of glass by heating together variously coloured pieces of glass, and drawing them out into rods. During the last few years ornamental articles of glass, such as paper-weights, etc., made on this principle, have come into extensive use. Damaskeened objects of intermixed steel and iron are frequently tinted of a beautiful brown by the application of particular liquids to the surface. I am indebted to Mr. Charles W. Lancaster, the well-known gunmaker of Bond Street, for the following receipt for damaskeening and colouring gun-barrels. I have witnessed the performance of the operation by Mr. Lancaster, and I do not remember to have anywhere seen more beautiful effects of this kind. The surface

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[8] By this expression I presume is meant the dusting with borax previously mentioned.

[9] Wilkinson. Engines of War. "On swords, bronze and iron; and on the cause of the pattern, or watering of the Damascus blades." p. 184 et seq.

is first carefully polished, and then coated with a thick mixture of whiting and water, which when dry is removed with a hard brush. This is done in order to cleanse the surface completely from oil. A small portion of a mixture, the receipt for which is given below, is next applied to the surface of the barrel by means of a sponge, and allowed to remain during 3 hours. The whole surface will now be found covered with rust, which is to be detached with a fine steel wire scratch-brush. After this the same process is repeated during 10 or 14 days. When a sufficiently dark colour has been communicated, the surface of the barrel is carefully scalded with boiling water, and when cold is rubbed over with the best sperm oil. In order to prepare the mixture, 1 drachm of corrosive sublimate (HgCl) is carefully mixed in a mortar with 2 fluid ounces of a solution of chloride of lime (hypochlorite), and allowed to stand 6 hours. To this mixture 10 drops of nitric acid are next added, and the whole is left at rest during 8 hours, when 1 quart of distilled water is added. The mixture is ready for use after the third day.

STRENGTH OF IRON AND STEEL.

The following tables contain abstracts of the principal series of experiments that have been made in England on the mechanical resistance of cast-iron, wrought-iron, and steel.

Table I., taken from the Minutes of the Proceedings of the Institution of Civil Engineers for the year 1844, contains the results of experiments on the transverse strength of 52 different samples of pig-iron. It is abstracted from a larger series published in the 'Memoirs of the Manchester Literary and Philosophical Society,' vol. vi. p. 273. The results exhibited in this table are the weights necessary to break bars of 1 inch square and 4 ft. 6 in. long, when supported at both ends and loaded in the centre, and the ultimate deflection from the horizontal line at the centre produced by such treatment before fracture.

Table II. contains the means of an elaborate series of experiments conducted at the Royal Arsenal, Woolwich, in the years 1856-59, on various qualities of pig-iron, to determine their resistance to transverse, tensile, and crushing strains. The data contained are the following:—

1. Transverse strength. This is generally determined by taking the mean of 12 values derived from breaking:—

2	bars	cast	vertically	and cooled	quickly
2	,,	,,	,,	,,	gradually
2	,,	,,	,,	,,	slowly

—and 3 sets of 2 each cooled in a similar manner, but cast horizontally. These bars were 22 in. in length and 2 in. square. The breaking weights in the table are those necessary for breaking a bar of 1 in. in the side at a distance of 1 inch from the point of support. The values in Table I. may be brought up to this standard by multiplying them by 13·5. The ultimate deflection is that registered by a self-acting apparatus at the moment of fracture.

2. Tensile strength. This was determined by tearing asunder short columns of 1·3 in. in smallest diameter. The tabular value is in most cases a mean of 18 results. The ultimate extension before fracture is that of a column 1·8 in. in height, and is only approximately correct.

3. The torsion strength was determined on round bars 8 in. between the points of support, and 1·8 in. in diameter. The angular value is the amount of twist in the bar at the moment of fracture. The result is compounded of six experiments, one from each of the six groups of three bars employed in the transverse and tensile testing.

4. The crushing strains are deduced from experiments on cylinders 1·3 in. high and 0·6 in. in diameter. Each is a mean of six results arranged in a similar manner to those of the former series.

Table III. contains the results of a series of experiments by Mr. W. Fairbairn, taken from the Report of the British Association for the year 1853, on the effect of repeated meltings on the transverse strength and resistance to crushing of cast-iron. The resistance to transverse strains is exhibited in a similar manner to that in Table I., the weight necessary to break a bar 1 in. square and 4½ ft. long between the points of support when loaded in the centre. These values require to be multiplied by 13·5 to bring them up to the standard of transverse strength adopted in the Woolwich experiments. In a few instances the proportion of sulphur, silicon, and carbon in the samples, as determined by Professor C. Calvert, is given. As fusion was effected in a cupola with coke as the fuel, it is obvious that in the course of remelting the iron might have suffered important chemical changes in composition, which may greatly modify its qualities. It is hardly conceivable that *simple remelting*, without the addition of anything to, or the subtraction of anything from, the metal, should produce any decided effect.

Tables IV., V., VI., VII., and VIII. contain the general results of an elaborate series of experiments on the tensile strength of various descriptions of wrought-iron and steel bars and plates made by Mr. D. Kirkaldy, and which have been published *in extenso* in his 'Experimental Enquiry'[1] on the tensile strength and other properties of various kinds of wrought-iron and steel. The second column contains the amount by which the area of the fracture varied from the original area of the specimen, or the contraction produced by the straining force. This is an important element as indicating the working qualities of the metal. The specimens in which the contraction is greatest are generally the toughest and softest, requiring to be slowly torn asunder, the increasing weight being thus borne by a constantly diminishing surface; while, on the other hand, harder specimens may sustain a greater absolute weight, but owing to their resistance to traction they retain their original area, with very slight diminution, to the last, and break suddenly with a snap or jerk.

[1] I have already referred to this excellent work, which ought to be in the possession of every Civil Engineer. A second edition, I am glad to find, has appeared.

Table I.

Results of Experiments on Hot and Cold Blast Pig-Iron, from the principal Iron-works of the United Kingdom, etc. (Fairbairn, Inst. C. E. 1844.)

No.	Names.		Specific Gravity.	Breaking weight in lbs. per sq. in.	Ultimate deflection of bars 54·0 in. long.
1	Ponkey............	No. 3 cold blast	7·122	581	1·747
2	Devon	No. 3 hot ,,	7·251	537	1 090
3	Cleator............	cold ,,	7·296	537	1·001
4	Oldbury	No. 3 hot ,,	7·300	530	1·005
5	Carron	No. 3 hot ,,	7·056	527	1·365
6	Beaufort	No. 3 hot ,,	7·069	517	1·599
7	Butterley	No. 3 hot ,,	7·038	502	1·815
8	Bute...............	No. 1 cold ,,	7·066	491	1·764
9	Windmill End...	No. 2 cold ,,	7·071	489	1·581
10	Old Park.........	No. 2 cold ,,	7·049	485	1·621
11	Beaufort	No. 2 hot ,,	7·108	474	1·512
12	Low Moor	No. 2 cold ,,	7·055	472	1·852
13	Buffery	No. 1 cold ,,	7·079	463	1·550
14	Brymbo	No. 2 cold ,,	7·017	459	1·748
15	Apedale	No. 2 hot ,,	7·017	456	1·730
16	Oldbury	No. 2 cold ,,	7·059	455	1·811
17	Pentwyn	No. 2	7·038	455	1·484
18	Maesteg	No. 2	7·038	454	1·957
19	Muirkirk.........	No. 1 cold ,,	7·113	453	1·734
20	Adelphi	No. 2 cold ,,	7·080	449	1·759
21	Blaina	No. 3 cold ,,	7·159	448	1·726
22	Devon	No. 3 cold ,,	7·285	448	0·790
23	Garthsherry ...	No. 3 hot ,,	7·017	447	1·557
24	Frood	No. 2 cold ,,	7·031	447	1·825
25	Lane End	No. 2	7·028	444	1·414
26	Carron	No. 3 cold ,,	7·094	443	1·336
27	Dundyvan	No. 3 cold ,,	7·087	443	1·469
28	Maesteg		7·038	442	1·887
29	Corbyn's Hall ...	No. 2 cold ,,	7·007	442	1·687
30	Pontypool.........	No. 2	7·080	440	1·857
31	Wallbrook	No. 3	6·979	440	1·443
32	Milton	No. 3 hot ,,	7·051	438	1·368
33	Buffery	No. 1 hot ,,	6·998	436	1·640
34	Level	No. 1 hot ,,	7·080	432	1·516
35	Pant...............	No. 1 hot ,,	6·975	431	1·251
36	Level	No. 2 hot ,,	7·031	429	1·358
37	W. S. S.	No. 2	7·041	429	1·339
38	Eagle foundry...	No. 2 hot ,,	7·038	427	1·512
39	Elsecar	No. 2 cold ,,	6·928	427	2·224
40	Varteg............	No. 2 hot ,,	7·007	426	1·450
41	Colsham	No. 1 hot ,,	7·128	424	1·532
42	Carroll	No. 2 cold ,,	7·069	419	1·231
43	Muirkirk	No. 1 hot ,,	6·953	418	1·570
44	Brierley	No. 2	7·185	418	1·222
45	Coed Talin	No. 2 hot ,,	6·969	416	1·882
46	Blackbarrow ...	cold ,,	7·172	416	1·736
47	Coed Talin	No. 2 cold ,,	6·955	413	1·470
48	Sarnakoff.........	cold ,,	7·216	372	1·160
49	Monkland	No. 2 hot ,,	6·916	403	1·762
50	Lays Works ...	No. 1 hot ,,	6·957	392	1·890
51	Milton	No. 1 hot ,,	6·976	369	1·525
52	Plaskynaslon ...	No. 2 hot ,,	6·916	357	1·366

Table II.

Tabular Abstract of Experiments on the Mechanical Resistances of Cast-Iron, made at the Royal Arsenal, Woolwich.

No.	Names of Furnaces.	Brands.	Ores.	Fuel.	Fluxes.	Blast.	Sp. Gr.	Tensile. Breaking weight per square inch. lbs.	Tensile. Breaking weight per square inch. tons.	Tensile. Extreme extension. inches.	Transverse. Breaking weight per square inch. lbs.	Transverse. Breaking weight per square inch. tons.	Transverse. Extreme deflection. inches.	Torsional. Breaking strain per square in. lbs.	Torsional. Breaking strain per square in. tons.	Torsional. Extreme angle of deflection. degrees.	Crushing. Crushing weight per square inch. lbs.	Crushing. Crushing weight per square inch. tons.
1	Hæmatite Foundry, Whitehaven.	No. 1 Foundry pig.	Red Hæmatite	Coke	Carboniferous limestone and coal shale.	. .	7·097	14,233	6·35	0·011	4,644	2·07	0·161	3,724	1·66	7·2	52,136	23·28
2	. .	,, 3 ,,	. .	. .	. .	. .	7·214	17,751	7·93	0·012	5,105	2·28	0·120	4,182	1·87	5·8	82,265	36·73
3	. .	,, 4 ,,	. .	. .	. .	. .	7·196	17,566	7·84	0·012	6,100	2·72	0·152	4,977	2·22	4·9	82,583	36·87
4	Ulverstone (Harrison, Ainslie, & Co.)	Ulverstone Iron	Red Hæmatite	Charcoal	. .	. .	..	..	..	..	5,005	2·49	..	..	..	..	..	..
5	. .	Do. remelted pig.	. .	. .	. .	. .	7·330	17,592	7·85	..	6,077	2·71	..	..	..	..	..	..
6	Weardale Iron Company.	No. 1 Pig-iron	Spathic ore, partly altered into brown iron ore.	Coke	Carboniferous limestone.	. .	7·088	18,080	8·07	0·010	5,600	2·50	0·147	5,510	2·46	10·1	59,771	26·68
7	. .	,, 3 ,,	. .	. .	. .	. .	7·158	21,859	9·76	0·011	7,374	3·29	0·181	5,968	2·66	7·7	90,046	40·20
8	. .	,, 4 ,,	. .	. .	. .	. .	7·248	23,513	10·50	0·009	7,672	3·43	0·173	6,350	2·83	7·2	109,286	48·79
9	. .	Remelted	. .	. .	. .	. .	7·180	30,332	13·54	0·012	8,948	3·99	0·191	6,277	2·80	5·2	122,216	54·56
10	South Bank Furnaces, Middlesboro'-on-Tees.	No. 2 Toughened pig, Calvert's patent.	Siliceous green carbonate of the Cleveland hills.	Purified coke.	Permian limestone (Dolomite).	. .	7·089	18,425	8·23	0·008	6,260	2·79	0·110	6,405	2·86	5·7	86,886	38·79
11	. .	No. 2 Foundry-pig.	. .	. .	. .	. .	7·023	15,835	7·07	0·006	5,563	2·48	0·105	5,626	2·51	6·5	77,926	34·79
12	Stockton Iron-works	No. 1 Hot-blast	Cleveland ironstone and red hæmatite.	Coke	Carboniferous limestone.	Hot-blast.	7·148	25,810	11·52	0·011	7,159	3·20	0·136	5,872	2·62	4·2	99,524	44·43
13	Do.	,, 3 ,,	. .	. .	. .	. .	7·135	22,721	9·94	0·009	6,932	3·09	0·134	6,305	2·81	5·7	87,063	38·87
14	Bowling Iron-works	Gun mixture ...	Clay ironstones of the coal-measures.	Coke	. .	Cold-blast.	7·233	27,838	12·43	..	10,095	4·51	..	..	..	..	..	..

15	. .	Deadhead	Clay ironstones of the coal-measures.	. .	. .	. .	7·233	26,896	12·01	..	9,386	4·19	..	..	..	..	..	..
16	. .	No 2, 1st sample		. .	. .	. .	7·154	15,600	6·96	..	6,347	2·83	..	..	..	..	..	..
17	. .	,, 3 ,,	. .	. .	. .	. .	7·046	17,530	7·83	..	5,012	2·24	..	..	..	..	..	..
18	. .	,, 2, 2nd do.	. .	. .	. .	. .	7·263	26,821	11·97	..	8,999	4·02	..	..	..	..	..	..
19	. .	,, 3, ,,	. .	. .	. .	. .	7·289	29,344	13·10	..	10,016	4·47	..	..	..	..	..	..
20	Butterley Iron-works.	,, 1 Foundry-pig.	. .	Coal...	Carboniferous lime-stone.	Hot-blast.	7·141	23,388	10·44	0·010	7,106	3·17	0·145	7,342	3·23	9·3	88,488	39·50
21	. .	,, 2 ,,	. .	. .	. .	. .	7·078	18,970	8·47	0·010	6,077	2·71	0·128	6,011	2·68	7·5	74,743	33·37
22	. .	,, 3 ,,	. .	. .	. .	. .	7·126	23,265	10·39	0·009	6,692	2·99	0·130	6,940	3·10	7·5	91,661	40·92
23	. .	,, 3 Blue rake	. .	. .	. .	. .	7·073	24,126	10·77	0·010	7,364	3·29	0·153	6,371	2·84	6·4	97,041	43·32
24	. .	Low's patent...	. .	. .	A patent flux, containing peroxide of manganese, graphite, and nitre, used in small quantities in the blast-furnace.	. .	7·186	25,185	11·24	0·009	7,914	3·53	0·145	4,761	2·13	3·9	125,198	55·89
25	West Hallam Iron-works, Ilkeston, Derbyshire.	No. 1 melting-pig.	. .	⅓ coal. ⅔ coke.	Carboniferous lime-stone.	Hot-blast.	7·121	22,107	9·87	0·012	7,587	3·39	0·153	7,312	3·26	8·1	82,229	36·71
26	. .	,, 2 ,,	. .	. .	. .	. .	7·217	29,840	13·32	0·014	9,033	4·04	0·172	8,113	3·62	8·0	119,483	53·34
27	. .	,, 3 ,,	. .	. .	. .	. .	7·239	30,115	13·44	0·013	9,399	4·20	0·157	7,973	3·56	8·6	120,321	53·71
28	. .	Grey forge-pig	. .	. .	. .	. .	7·166	25,380	11·33	0·012	7,751	3·46	0·142	7,711	3·44	8·3	99,193	44·28
29	. .	No. 4 strong forge.	. .	. .	. .	. .	7·117	19,847	8·56	0·010	7,173	3·20	0·159	6,403	2·86	8·7	75,318	33·62
30	Goldendale Iron-works, N. Staffordshire.	Pig-iron	. .	Coal...	Carboniferous lime-stone.	. .	7·096	25,430	11·35	0·008	7,591	3·39	0·132	6,837	3·05	4·5	113,459	50·65
31	Netherton Iron-works.	No. 1 melting foundry-pig.	. .	Coke	Silurian limestone	Cold-blast.	7·125	20,517	9·16	0·010	6,954	3·10	0·166	6,130	2·74	14·4	73,977	33·02
32	. .	,, 2 ,,	. .	. .	. .	. .	7·175	26,012	11·61	0·011	8,139	3·63	0·196	7,186	3·21	14·9	86,473	38·60
33	. .	,, 3 grey forge	. .	. .	. .	. .	7·161	24,222	10·81	0·012	7,634	3·41	0·177	6,204	2·77	14·5	82,406	38·79
34	. .	Nos. 4 & 5 forge	. .	. .	. .	. .	7·217	30,344	13·55	0·014	9,619	4·29	0·200	7,570	3·38	14·1	108,285	48·34
35	. .	No. 5, strong forge.	. .	. .	. .	. .	..	..	..	..	8,129	3·63	0·123	..	..	..	..	..
36	Parkhead Furnaces, Dudley.	Foundry melting-pig.	. .	Coke	Silurian limestone	Cold-blast.	7·195	27,033	12·06	0·011	7,778	3·47	0·168	7,226	3·22	16·2	95,787	42·76
37	. .	Grey forge	. .	. .	. .	. .	7·082	18,831	8·41	0·010	5,998	2·68	0·144	5,969	2·66	10·6	69,733	31·12
38	. .	Forge	. .	. .	. .	. .	7·193	30,554	13·64	0·013	8,840	3·95	0·183	7,697	3·44	11·7	107,223	47·87

TABLE II.—*continued.*

Tabular Abstract of Experiments on the Mechanical Resistances of Cast-Iron, made at the Royal Arsenal, Woolwich—*continued.*

No.	Names of Furnaces.	Brands.	Ores.	Fuel.	Fluxes.	Blast.	Sp. Gr.	Tensile. Breaking weight per square inch.		Tensile. Extreme extension.	Transverse. Breaking weight per square inch.		Transverse. Extreme deflection.	Torsional. Breaking strain per square in.		Torsional. Extreme angle of deflection.	Crushing. Crushing weight per square inch.	
								lbs.	tons.	inches.	lbs.	tons.	inches.	lbs.	tons.	degrees.	lbs.	tons.
39	Old Hill Furnaces, near Dudley.	No. 2 foundry-pig	Clay ironstone of the coal-measures and Ulverstone hæmatite.	Coke	Silurian limestone, Springfield.	. .	6·949	14,593	6·51	0·009	5,192	2·32	0·133	4,642	2·07	10·1	50,499	22·54
40	. .	,, 3 grey forge	. .	. .	. .	. .	7·111	23,815	10·63	0·011	7,478	3·34	0·167	7,147	3·19	13·5	80,991	36·16
41	. .	,, 4 forge......	. .	. .	. .	. .	7·058	22,918	10·23	0·012	6,926	3·09	0·157	5,757	2·57	8·5	80,213	35·81
42	. .	Strong forge ...	. .	. .	. .	. .	7·143	27,676	12·36	0·011	7,793	3·48	0·153	5,861	2·62	6·1	119,807	53·49
43	Lays Iron-works, near Dudley.	Hæmatite iron, 1st melting.	Ulverstone hæmatite and Forest of Dean brown iron ore, & clay ironstones	Coke	Carboniferous and Upper Silurian limestones in equal proportions.	. .	7·253	31,480	14·05	0·012	8,142	3·63	0·171	5,071	2·26	5·1	119,631	53·41
44	Level Iron-works, Brierley Hill.	Hot-blast pig...	Clay ironstones......	Coke	Silurian limestone...	Hot-blast.	7·143	26,198	11·69	0·13	7,254	3·24	0·145	5,879	2·62	5·7	99,795	44·55
45	. .	Cold-blast pig...	. .	. .	. .	Cold-blast.	7·052	25,872	11·55	0·13	6,903	3·08	0·129	5,654	2·52	6·2	86,650	38·68
46	Lilleshall Iron-works, Salop.	Price & Nicholson's patent iron.	Made of a mixture of cold-blast pig and metal from the refinery.	. .	. .	. .	7·259	28,960	12·93	..	9,120	4·07	..	..	..	..	..	..
47	East End Works, Wellingborough, Northamptonshire.	No. 1 grey foundry-pig.	Oölitic brown iron ore.	Coal...	Oölitic limestone and chalk.	Cold-blast.	7·185	20,105	8·98	0·008	5,744	2·56	0·107	5,424	2·42	3·4	105,395	47·05
48	. .	,, 2 mottled iron.	. .	. .	. .	. .	..	..	..	..	4,869	2·17	0·082	..	..	..	..	..

49	Heyford Iron-works, near Weedon, Northamptonshire.	Pig-iron, 1st melting.	Oölitic brown iron ore.	Coke	Oölitic limestone ...	. .	6·886	10,866	4·85	0·002	3,075	1·37	0·082	3,905	1·74	1·9	77,690	34·68
50	Park End Furnaces, near Lydney, Gloucestershire.	Foundry pig ...	Hæmatite partly mixed with carbonate of lime.	Coke	Calcined shale of the coal-measures.	. .	7·115	12,593	5·62	0·009	5,220	2·33	0·180	4,478	1·99	11·5	56,116	25·05
51	. .	Grey-forge	. .	. .	. .	. .	7·176	17,019	7·60	0·009	6,781	3·03	0·167	6,232	2·78	10·5	73,400	32·77
52	Ystalyfera Iron-works, Glamorganshire.	No 1 foundry-pig, 2nd melting.	Clay ironstone of the coal-measures, and Ulverstone hæmatite.	Anthracite.	Carboniferous limestone.	. .	7·165	25,172	11·24	0·011	7,848	3·50	0·163	6,704	2·99	12·2	87,475	39·05
53	. .	,, 2 ,,	. .	. .	. .	. .	7·157	26,758	11·95	0·013	7,944	3·55	0·196	6,176	2·76	9·6	90,894	40·58
54	. .	,, 3 foundry-pig, 2nd melting	. .	. .	. .	. .	7·150	24,533	10·95	0·012	7,228	3·23	0·166	5,719	2·55	8·8	88,772	39·63
55	. .	No. 1 1st ,,	. .	. .	. .	. .	7·132	25,311	11·30	0·013	7,656	3·42	0·174	6,265	2·80	12·4	87 570	39·09
56	. .	,, 2 ,,	. .	. .	. .	. .	7·132	21,661	9·67	0·012	7,206	3·22	0·175	6,559	2·93	12·1	77,573	34·63
57	. .	,, 3 ,,	. .	. .	. .	. .	7·153	23,707	10·58	0·012	7,785	3·48	0·188	6,894	3·08	13·3	85,094	37·99
58	Blaenavon Iron-works, Monmouthshire.	No. 1 and common forge.	Clay ironstones of the coal-measures.	Coke	Carboniferous limestone.	Cold-blast.	7·163	26,766	11·95	0·011	7,947	3·56	0·182	5,487	2·45	6·1	105,203	46·97
59	. .	No. 1	. .	. .	. .	. .	7·137	25,456	11·36	0·012	7,493	3·35	0·171	5,034	2·25	9·0	91,897	41·03
60	. .	Common forge	. .	. .	. .	. .	7·268	28,637	12·78	0·009	7,805	3·48	0·144	5,953	2·66	4·4	130,860	58·42
61	. .	No. 3...	. .	. .	. .	. .	7·158	23,903	10·67	0·011	7,600	3·39	0·191	5,674	2·53	10·2	87,358	38·99
62	. .	Bright	. .	. .	. .	. .	7·150	23,139	10·33	0·009	6,594	2·94	0·120	3,882	1·73	2·9	126,086	56·29
63	Pontypool Iron-works, Monmouthshire.	Cold-blast iron	Clay ironstone	Coke	.	Cold-blast.	7·169	26,302	11·74	0·015	6,669	2·98	0·144	5,235	2·34	5·3	99,618	44·47
	FOREIGN.																	
64	Begbie's, Swedish...	Grey pig.........	. .	. .	. .	. .	..	..	..	..	5,673	2·53	..	..	..	..	..	..
65	Acadian Iron Company.	Grey pig.........	. .	. .	. .	. .	7·209	23,194	10·35	0·011	8,092	3·61	0·202	7,726	3·45	22·5	86,933	38·81
66	. .	White pig	. .	. .	. .	. .	..	..	..	..	4,141	1·85	0·066	..	..	..	..	..
67	Townsend's "Sterling," New York.	No. 1 sterling pig.	Magnetite	Charcoal	. .	. .	7·181	23,613	10·54	0·011	8,210	3·67	0·213	5,734	2·56	9·8	84,410	37·68
68	East Indian Iron Company.	Charcoal pig ...	. .	Charcoal	. .	Cold-blast.	..	..	..	..	4,120	1·84	0 086	..	..	..	..	..
69	Elba Iron	. .	. .	. .	.	. .	..	..	..	..	4,249	1·90	..	..	..	..	..	..
70	Tuscan Iron	. .	. .	. .	.	. .	..	..	..	..	3,934	1·76	..	..	..	..	..	..

TABLE [illegible]

[illegible]

[illegible]

Number of [illegible]	Specific gravity	[illegible]	[illegible]	[illegible]	Breaking weight [illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]				[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	35·[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1·[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	1 [illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	2·22	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLES IV TO VIII, *inclusive*.—ABSTRACT OF MAIN RESULTS OF EXPERIMENTS ON THE TENSILE STRENGTH OF WROUGHT-IRON BARS, PLATES, AND ANGLE-IRON; STEEL BARS AND PLATES. (From Kirkaldy's Experiments.)

TABLE IV.

ROUND AND SQUARE BARS.

	Districts and Brands.	No. of experiments.	Specific gravity.	Breaking strain per square inch. lbs.	Breaking strain per square inch. tons.	Contraction of area per cent.
1	Yorkshire, *Low Moor*, *Bowling*, *Farnley*	20	7·760	61,64[illegible]	27·5	49·8
2	Lanarkshire ◇ GOVAN ◇ ...	12	7·720	58,181	26·0	49·4
	Do. Extra B Best Best scrap	30	7·683	57,411	25·6	39·9
	Do. Best Best B Best B Rivet	61	7·658	58,737	26·2	36·0
	Do. Best ◆	24	..	58,265	26·0	22·6
3	Staffordshire charcoal (L)	4	..	57,216	25·6	60·9
	Do. B B scrap	4	..	59,370	26·5	52·0
	Do. ♛ B. C. ♛ Best Best Best	21	7·680	58,698	26·2	39·5
	Do. ♛ Best K. B. M.	4	..	55,000	24·6	27·0
4	Lancashire Best Rivet	8	..	53,775	24·0	48·6

Table V.

Beam, Strap, and Angle Iron.

	Districts and Brands.	No. of experiments.	Specific gravity.	Breaking strain per sq. in. lbs.	Breaking strain per sq. in. tons.	Contraction of area per cent.
1	Low Moor, Farnley, Bowling	4	7·728	61,260	27·4	41·4
2	Lanarkshire Extra B Best Best scrap	6	7·571	56,094	25·0	20·1
	Do. Best Best B Best Best Rivet	24		54,930	24·5	16·8
	Do. Best *	3		45,439	20·3	9·2
3	Staffordshire S. C. Best Best Best	12	7·539	54,558	24·4	18·2
	Do. Best K. B. M.	9		51,227	22·9	17·7
4	Durham Best Best..............	6	7·633	53,548	23·9	18·3
	Do.	4		50,807	22·6	11·7
5	South Wales	4	7·531	41,386	18·5	9·8

Table VI.

Plates.

L. signifies lengthways, C. crossways.

	Districts and Brands.	No. of experiments. L.	No. of experiments. C.	Specific gravity.	Breaking strain per sq. in. L. lbs.	tons.	C. lbs.	tons.	Contraction of area per cent. L.	C.
1	Low Moor, Farnley, Bowling	21	24	7·732–·699	54,980	24·6	50,540	22·6	20·9	12·8
2	Lanarkshire ◇ GOVAN ◇	6	6	7·675	54,644	24·4	49,399	22·1	18·1	8·5
	Do. Extra B Best Best scrap	4		..	50,844	22·7	..	..	13·0	
	Do. Best Best B Best B Rivet	38	34	..	49,077	21·9	43,359	19·4	8·2	4·4
	Do. Best *...	18	18	7·541	46,438	20·7	41,527	18·5	6·9	3·7
3	Staffordshire S C Best Best Best	30	29	7·570–·619	52,168	23·3	48,840	21·8	12·9	7·8
	Do. Best K B M	8	8	..	45,686	20·4	44,748	19·9	9·4	6·6
4	Shropshire Best............	5	5	7·580	52,362	23·4	43,036	19·2	15·0	5·3
5	Durham Best Best............	37	38	7·613	51,308	22·9	46,381	20·7	12·9	7·4

Table VII.

Steel Bars.

F. signifies forged, R. rolled.

	Names.		No. of experiments.	Specific gravity.	Mean breaking weight per square in.		Contraction of area per cent.
					lbs.	tons.	
1	Turton's cast-steel for tools......	F.	6	..	132,909	59·3	4·7
2	Jowitt's do.	F.	4	..	132,402	59·1	12·8
3	Do. do. chisels...	F.	8	7·823	124,852	55·7	17·0
4	Do. double shear-steel	F.	4	..	118,468	52·9	19·6
5	Do. cast-steel for drifts......	F.	4	..	115,882	51·7	21·5
6	Bessemer's patent steel for tools	F.	8	7·821	111,460	49·8	22·3
7	Moss and Gamble's cast-steel for rivets	R.	4	..	107,286	47·9	32·1
8	Naylor, Vickers, and Co. do....	R.	4	..	106,615	47·6	32·8
9	Wilkinson's blister-steel	F.	4	7·720	104,298	46·6	21·4
10	Jowitt's cast-steel for taps	F.	4	..	101,151	45·2	28·8
11	Krupp's do. bolts	R.	4	..	92,015	41·1	34·0
12	Shortridge and Co.'s Homogeneous metal	R.	4	..	90,647	40·4	36·6
13	Do. do.	F.	4	..	89,724	40·1	26·0
14	Jowitt's spring steel	F.	4	..	72,529	32·4	24·1
15	Mersey Company's puddled steel	F.	6	..	71,486	31·9	35·3
16	Blochairn do.	R.	6	7·707	70,166	31·3	19·4
17	Do. do.	F.	6	..	65,255	29·1	19·0
18	Do. do.	F.	4	..	62,769	28·0	11·9

Table VIII.

Steel Plates.

L. signifies lengthways, C. crossways.

	Names and thicknesses.	in.	Position.	No. of experiments.	Specific gravity.	Mean breaking weight per square in.		Contraction of area at fracture per cent.
						lbs.	tons.	
1	Turton and Son's cast-steel ...	$\frac{1}{4}$	L.	4	7·815	94,289	42·1	5·6
2	Do. do.	,,	C.	4		96,308	42·9	13·4
3	Shortridge and Co. do.	$\frac{3}{16}$	L.	5	7·802	96,280	43·0	15·6
4	Do. do.	,,	C.	5		97,150	43·4	14·8
5	Naylor, Vickers, and Co. do.	$\frac{1}{4}$	L.	6	7·825	81,719	36·5	21·4
6	Do. do.	,,	C.	6		87,150	38·9	22·0
7	Moss and Gamble's do.	$\frac{3}{16}$ $\frac{4}{16}$	L.	7	7·822	75,594	33·7	28·2
8	Do. do.	,,	C.	3		69,082	30·9	38·6
9	Shortridge and Co. do.	$\frac{3}{8}$	L.	1	..	96,989	43·3	14·4
10	Mersey Co. puddled steel	$\frac{3}{16}$ $\frac{3}{16}$	C.	4	..	101,450	45·3	6·4
11	Do. do.	,,	L.	4	..	84,968	37·9	4·4
12	Do. hard puddled steel	$\frac{1}{4}$	C.	8	..	102,593	45·8	4·5
13	Do. do.	,,	L.	2	..	85,365	38·1	4·7
14	Blochairn puddled	$\frac{3}{16}$	C.	5	7·640 to 7·667	102,234	45·6	5·3
15	Do.	,,	L.	5		84,398	37·7	4·2
16	Do.	$\frac{4}{16}$	C.	2		96,320	43·0	10·4
17	Do.	,,	L.	2		73,699	32·9	3·8
18	Shortridge and Co. do.	$\frac{1}{4}$	C.	4	7·683	72,408	32·3	11·5
19	Do. do.	,,	L.	2		73,580	32·8	5·7
20	Mersey Company mild do. ...	$\frac{1}{4}$	C.	2		77,046	34·4	12·5
21	Do. do. ...	,,	L	2	..	67,686	30·2	8·5
22	Do. do. ...	$\frac{9}{32}$	C.	2	..	71,532	31·9	7·5

TABLE IX.

EXPERIMENTS ON THE TENSILE STRENGTH OF BOILER-PLATES AT VARIOUS TEMPERATURES, by W. FAIRBAIRN, F.R.S.

(From the Report of the British Association, 1856.)

The plates experimented on were Staffordshire boiler-plates of ordinary quality.

Temperature, Fahr.	Breaking strains			
	In the direction of the fibre.		Across the fibre.	
	Per square inch in lbs.	Per square inch in tons.	Per square inch in lbs.	Per square inch in tons.
degrees				
0	49,009	21·88	..	..
60	50,219	22·41	41,881	18·69
114	41,356	18·46	44,160	19·71
212	44,717	19·96	45,680	20·39
270	44,020	19·65	..	..
340	49,968	22·31	42,088	18·79
395	46,086	20·57	..	..
Red-heat	..	..	34,272	15·30

TABLE X.

EXPERIMENTS ON THE TENSILE STRENGTH OF RIVET-IRON AT VARIOUS TEMPERATURES, by W. FAIRBAIRN, F.R.S.

(Op. cit. ut supra.)

Temperature, Fahr.	Mean breaking weight	
	Per square inch. in lbs.	Per square inch in tons.
degrees.		
−30	63,239	28·26
60	62,816	28·05
114	70,845	31·61
212	79,271	35·39
250 - 270	82,636	36·89
310 - 325	84,046	37·52
415 – 435	83,943	37·47
Red-heat	35,000	15·62

The maximum strength of rivet-iron appears to be attained at a temperature of 320° Fahr. This is above the temperature at which the maximum strength of plates was attained, but little or no alteration of strength is observable in plates, while that of bars is increased nearly one-half. The iron was of good quality, made from carefully-selected scrap-iron.

Permanent Expansion of Cast-iron by Exposure to long-continued Heat, at or above Redness.

This fact has long been known. It was particularly mentioned by Dr. Thomas Beddoes in a paper communicated to the Royal Society in 1791.[1] "In annealing crude iron, with or without charcoal," the author states, "it is well known to increase in all its dimensions. I have seen bars originally straight bent like an S, when long exposed to heat in circumstances where they could not extend themselves endways."

In 1829 Mr. Prinsep announced that cast-iron became permanently increased in bulk after having been strongly heated. He found that the capacity of a cast-iron retort heated twice was augmented each time. The capacity was determined from the weight of pure mercury which the retort contained at 80° F. The results are as under:—[2]

	Capacity in cubic inches.
Before the first experiment	9·13
After the first heating	9·64
After three heatings	10·16

Guettier, in experiments on chill-casting, ascertained that small bars of white, as well as grey, pig-iron cast in iron moulds were slightly elongated by heating to redness; but a bar of white pig-iron cast in a sand mould was slightly shortened by the same treatment.[3]

Brix found that the cast-iron bars of a steam-boiler furnace increased in length, but in a diminishing ratio, after each reheating for a certain number of times, when at last their length became constant. A bar 3¼ ft. long, after 3 days' use in a gentle fire, was lengthened $\frac{3}{16}$ in.; on the seventeenth day the elongation amounted to $\frac{7}{16}$ in.; after thirty days it was ¾ in., or nearly 2%, and did not then even appear to have reached its maximum. Another bar of the same kind, after continued use, increased 1¼ in. in length, or nearly 3%.[4] Hence it was concluded that in new bars ⅛ in. play should be allowed for every foot in length, *i.e.*, $\frac{1}{96}$ of the total length.

At my request, Mr. John James, furnace manager of the Blaina Iron-works, made the following experiment (Nov. 1859). A bar of foundry iron, 4 ft. 8 in. long and 1 in. square, was placed in one of the hot-blast ovens, heated by the waste gas of the blast-furnaces. After 54 hours it was increased ½ in. in length. On again exposing it in the same oven, during a period of 168 hours, it was further permanently elongated $\frac{1}{16}$ in. As the surface had now become much oxidised and peeled off, it was not possible to determine whether the bar had expanded transversely.

Advantage has been taken of this permanent increase in volume which cast-iron acquires by long exposure to a high temperature, in rendering cannon-shot serviceable which had been cast too small.

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[1] Read March 24. p. 179.

[2] Brewster's Edinb. Journ. of Science. 1829. 10. p. 356.

[3] Berg-u.-Huttenm. Zeit. 1848. 7. p. 8. Quoted from the Moniteur Industriel, Oct. 1847.

[4] Berg-u.-Hüttenm. Zeit. 1854. 13. p. 12.

The shot were heated in a charcoal fire, well imbedded in the charcoal, and allowed to cool under charcoal dust. Their surface was bluish grey, and did not require any cleaning to fit the shot for use; whereas, in previously attempting to employ a hot-blast oven for the same purposes, the surface became coated with firmly adherent red oxide, so difficult to detach that it was found preferable to recast the shot than incur the labour and expense of cleaning them.[5]

Dilatation of Cast-iron by Heat.

Generally in foundries the amount allowed for contraction of grey pig-iron after fusion is 1%, so that patterns should be made larger in that proportion.[6] In white pig-iron the contraction after fusion is greater, being from 2% to $2\frac{1}{2}\%$ of the length of the object.

SKETCH OF THE HISTORY OF IRON.

In the course of this volume, the History of the Art of Extracting Iron from its Ores, and preparing it in the several states of malleable iron, steel, and cast-iron, for the immediate use of artificers of all kinds, has been gradually and completely unfolded. I have reserved for present consideration two subjects, namely, the employment of the metal by the ancients, and the development of the Smelting of Iron in this country with pit-coal.

From suitable ore, of which abundant and readily accessible supplies exist in various localities, nothing more easy can be conceived than the extraction of malleable iron. Of all metallurgical processes it may be regarded as amongst the most simple. Thus, if a lump of red or brown hæmatite be heated for a few hours in a charcoal fire, well surrounded by, or imbedded in, the fuel, it will be more or less completely reduced, so as to admit of being easily forged at a red heat into a bar of iron. The primitive method of extracting good malleable iron directly from the ore, which is still practised in India and in Africa, requires a degree of skill very far inferior to that which is implied in the manufacture of bronze. The production of this alloy involves a knowledge of copper-smelting, of tin-smelting, and of the art of moulding and casting. From metallurgical considerations, therefore, it is reasonable to suppose that the so-called Age of Iron would have preceded the Age of Bronze. Archæologists, however, seem generally to have arrived at an opposite conclusion, mainly from the fact that, while ancient objects of iron are exceedingly rare, ancient objects of bronze are abundant. But it should be remembered that iron is very rapidly corroded by oxidation, even in dry climates, whereas bronze is very slowly acted upon even in moist climates. Hence, if objects of

[5] Berg-u.-Hüttenm. Zeit. 1855. 14. p. 189.

[6] Traité de la Fabrication de la Fonte et du Fer. Flachat, etc. 1842. 1. p. 70.

[illegible] in ancient times. [illegible] [illegible] have been long preserved [illegible] [illegible] [illegible] [illegible] [illegible].

The question whether the early Egyptians were acquainted with iron and employed it [illegible] in constructing their monuments has given rise to much discussion. This subject has recently been considered by Mr. A. Henry Rhind,[7] who concludes that [illegible] "between the epoch of the [illegible] and the [illegible] period of [illegible] iron had come to be [illegible] employed [illegible]," [illegible] in like manner, and within about the same interval—probably with an earlier commencement—the same metal was more or less abundantly [illegible] in Egypt." In the tomb of [illegible] which he explored and which he assigns reasons for believing had not been opened during nearly 2000 years previously, he discovered in the massive doors of the inner repositories hinges [illegible] "as sharp and as bright as on the day they left the forge." Hence he infers that the destruction of iron by rust cannot account for the fact that so few, if any, articles of iron should have been found amongst early Egyptian antiquities. He supports this inference by another fact, that implements of bronze used for ordinary purposes, such as chisels, etc., are common in our archæological collections. He does not attach much weight to the diversity of colours employed by the early Egyptians in depicting metallic objects; for in some instances objects identical in form are painted alternately green and red. This inquiry is one of great interest, but I have not yet studied the subject sufficiently to be able to arrive at a satisfactory conclusion. I may add that I have just received from Mr. Francis Galton specimens of black slag, not unlike iron slag, which have been recently found in "exceedingly ancient Sinaitic remains," conjectured to be anterior to the time of Moses.

That the Assyrians were well acquainted with iron is clearly established by the explorations of Mr. Layard, who has enriched the collection of the British Museum with many objects of iron from Nineveh of the highest interest. Amongst these may be particularly specified tools employed for the most ordinary purposes, such as picks, hammers, knives, and saws. There is a saw similar in construction to that now used by carpenters for sawing large pieces of timber across. It has been described and figured by Mr. Layard.[8] It consists of a blade 3 ft. 8 in. long and 4¼ in. broad throughout its entire length, except at one end, where it is narrowed, and was, no doubt, let into a handle of wood, the rivets being visible upon it. The other end was probably similar, but, unfortunately, it has been broken off. The metal seems to be almost wholly converted into oxide, yet sufficient remains strongly to attract the magnetic needle; that is, supposing no magnetic oxide of iron to be present. There is no evidence to show whether it ori-

[7] Thebes: its Tombs and their Tenants, ancient and present, including a record of Excavations in the Necropolis. 1862. Ch. viii. p. 217. Sebau appears to have been born B.C. 68, and to have died B.C. 9.

[8] Discoveries in the Ruins of Nineveh and Babylon. 1853. p. 195.

ginally consisted of iron or steel, though this point might possibly be ascertained by very careful chemical investigation. As an illustration of ancient metallurgy, there is no object in the Museum of greater interest than this rusted saw, which has only recently been exposed to public view. It was found in the North-West Palace at Nimroud; and it is computed that, while it could not be later in date than 880 B.C., it may have been considerably earlier. The fact of iron having been applied to common hammer-heads, for which bronze might have proved a tolerably good substitute, indicates that iron was certainly as cheap, if not cheaper, in those days than bronze; and the correctness of this inference is strikingly confirmed by many other objects from the same locality, consisting of cores of iron around which bronze has been cast. I examined one of these at the request of Mr. Layard, to whom I communicated a description, which was published in 1853, in the 'Discoveries in the Ruins of Nineveh and Babylon,'[9] and from which the following extract is presented:—

"It was a small casting, in the shape of the fore-leg of a bull. It formed the foot of a stand, consisting of a ring of iron, resting on three feet of bronze. It was deeply corroded in places, and posteriorly was fissured at the upper part. A section was made, which disclosed a central piece of iron, over which the bronze had been cast. At the upper part, where it had been broken off, the iron had rusted, and so produced the crack above mentioned. The casting was sound, and the contact perfect between the iron and surrounding bronze. It was evident on inspection that the bronze had been cast round the iron, and that the iron had not been let into the bronze; and in this opinion I am confirmed by Mr. Robinson, of Pimlico, who has had considerable experience in bronze casting. Some interesting considerations are suggested by this specimen.

"The iron was employed either to economize the bronze—for the purpose of ornament—or because it was required in the construction. If the former, iron must have been cheaper than bronze, and, therefore, probably more abundant than has been generally supposed. No satisfactory conclusion can be arrived at on this point from the fact that bronze antiquities are much more frequently found than those of iron; for the obvious reason, that bronze resists destruction by oxidation much better than iron."

I have recently examined the iron of the core, and found that it does not become sensibly harder by plunging it while red-hot into mercury.

Other Assyrian antiquities of iron, which deserve particular attention, are portions of chain armour and two helmets ornamented with bronze. These helmets are greatly corroded by rust, but they are sufficiently perfect in form to indicate excellence in the quality of the iron, and no ordinary skill in working the metal.

The early history of the art of extracting and working iron in this kingdom still remains obscure. However probable it may be, it is not

[9] Appendix, p. 670.

yet certain, that the Britons were acquainted with the use of iron and the mode of reducing its ores anterior to the invasion of Cæsar. But it seems to be well established that the Romans largely extracted iron, especially in the Forest of Dean [1] and the Weald of Sussex,[2] where vast accumulations of ancient iron slags occur, in which Roman coins and other antiquities have been found imbedded. Amongst the Sussex slags, coins of the date of Nero, Vespasian, and Dioclesian, together with numerous fragments of Roman pottery, have been discovered; and amongst those of the Forest of Dean, coins of the date of Trajan. The metal was obtained direct from the ore in the malleable state with charcoal as fuel; and by a method no doubt closely resembling, if not identical with, the Catalan process. The Roman method has been pronounced very imperfect, because the refuse slags contain a large percentage of iron. Yet the slags produced by the Catalan process are always of necessity equally rich in iron; and so are those formed in the modern South-Welsh charcoal finery process, and in the operation of puddling, which until recently were thrown away, or used to mend roads. That the old slags should have become valuable as a source of iron, after the discovery of cast-iron and the erection of high-blast furnaces, does not indicate that the Roman method of extraction of iron from its ores, sometimes erroneously termed *smelting*, was less perfect, *quà* method, than the modern processes of converting pig-iron into bar-iron. They did by one process, according to the *direct method*, what we now effect by two; and the slag which they produced should be compared not with our blast-furnace cinder, but especially with our finery, tap, and flue cinders.

With regard to the supposition that the ancient Britons were familiar with the use of iron, and knew how to extract it from its ores, Mr. Lower has made the following observations, which appear to me to have considerable force:[3]—"It is not improbable that the iron of Sussex was wrought in times even anterior to the conquest of this island by the Romans. Previously to the advent of Cæsar, the inhabitants of Britain must have made a considerable advance in the arts of civilization. To have subjugated the horse, and to have made such proficiency in many of the details of military science as the conqueror of Gaul found to his cost that they possessed, may well assert for them a degree of refinement quite at variance with the too generally received opinion that they were mere savages and barbarians. If the use of iron be taken as the point at which pure barbarism ends and civilization begins, the ancient Britons had certainly passed that point, as the formidable scythes attached to the axles of their chariots sufficiently prove, to say nothing of the chariots themselves, which

[1] The Forest of Dean; an Historical and Descriptive Account, derived from personal observation and other sources, public, private, legendary, and local. By H. G. Nicholls, M.A. 1858. p. 212 et seq. Vid. also a Lecture by the same Author to the Archæological Association, July 23, 1860.

[2] Contributions to Literature, Historical, Antiquarian, and Metrical. By Mark Antony Lower, M.A., F.S.A. 1854. p. 85 et seq. Historical and Archæological Memoir on the Iron-works of the South-east of England (particularly of Sussex).

[3] Op. cit. p. 93.

obviously [Is this obvious?] were not made without the use of iron tools. Cæsar mentions that the currency of the people consisted partly of *iron rings*, adjusted to a certain weight (*utuntur aut ære aut annulis ferreis, ad certum pondus examinatis, pro nummo*); and as he states, in the same breath, that their brass [bronze?] was imported (*ære utuntur importato*), it may reasonably be inferred that their iron was of home manufacture. And assuming that such was the case, the iron of our Wealds could hardly have escaped notice. However great the error of Cæsar in asserting that Britain produced but little iron (*nascitur ibi in maritimis* [*regionibus*] *ferrum; sed ejus exigua est copia*),[4] his allusion is useful as proving his knowledge of the fact that the island was not destitute of this invaluable mineral: and how he became acquainted with that fact, except from the information of the Britons themselves, it would be difficult to determine. It may be further remarked, that the 'maritime regions' referred to by him were, in all probability, the Wealds of Kent and Sussex."

M. Keller, President of the Society of Antiquaries at Zurich, has recently published an interesting account of blocks of malleable iron, which are rough on the surface, quadrangular, and bevelled off almost to a point at each end, so as to form a sort of double pyramid. They have been found in different parts of Switzerland, unaccompanied with furnace residua. They vary in weight from 10 lbs. to 16 lbs. Keller suggests that they may possibly be similar to the objects above referred to by Cæsar; that they were crude and roughly forged lumps produced in primitive Catalan forges, and were transported from a distance as articles of merchandise, to be wrought on the spot into the required forms.[5]

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[4] De Bell. Gall. lib. v. cap. 12.

[5] I insert the following interesting extract from *The Times* of Sept. 10, 1862:—

"DIGGINGS INTO ANCIENT BRITAIN.—Consecutive explorations of an unusual character have been made during the summer of the last and present years in the Cheviot district. On these lofty hills, sealed for so many months of the year with snow, yet clad in summer with ferns and mosses and short-set grass, with here and there a purple fox-glove, a mountain pink, or a scarlet-leaved bilberry, a veritable tract of ancient Britain has been laid bare: a walled town, several fortlets, scattered hut-circles and tumuli have been disencumbered of the earth that has been accumulating over them for nearly 2000 years; and many interesting facts have been thus disclosed respecting the Celtic tribes whom Cæsar found in possession of the land. It would appear that the Cheviot Hills were well populated in those remote times. Huge circles of masonry overgrown with herbage are seen on most of them, sometimes on the slopes, sometimes on the summits, and within many of these there are smaller circles of turf-covered stones marking sites of huts. In all these ramparts and dwellings blocks of the porphyry of the district have been used as the sole building material. On the southern slope of a hill, locally distinguished as Greenlaw, great masses of ruin promised a rich reward to the spade of the excavator. Here three walled inclosures, connected with one another by a roadway, have been brought to light. Within these inclosures traces of as many as seventy stone huts can be counted. Most of the entrances into these face the east, and the floors of those that have been dug into are found to have been rudely flagged with flattish porphyry stones. The largest of the inclosures has been strengthened with two ramparts; against the inner of these walls is a hut which has a flue—the earliest evidence of the use of chimneys we possess. A sunken fireplace was found to be formed about 18 inches below the flagging, from which a funnel conducted the smoke through the thickness of the rampart. Charred wood was found in the conduit. In several of the huts charred wood was found in the floors, as well as broken pottery; in one a glass bead, in another a

From the period when the extraction of iron from its ores was first practised until a few centuries ago at furthest, the art appears to have remained nearly stationary; and it could not have been otherwise so long as the direct process, or that by which the metal is obtained in the malleable state by one operation from the ore, was the only one known: for, in this process, as we have seen, only comparatively small quantities of ore can be successfully treated at a time; and it is so extremely simple in its nature as not to admit of any considerable improvement. The great step in advance was the discovery of cast-iron, and the invention of the high-blast furnace. We have traced the gradual transition from the Catalan hearth to this gigantic furnace, through the successive stages of the Osmund furnace and the German Stückofen, in which either a huge lump of malleable iron or cast-iron was produced at will by varying the proportions of ore and fuel constituting the charge.

The date of the discovery of cast-iron has not, so far as I am aware, been precisely ascertained, though it is a point of great archæological interest. Lower has published the following remarkable statement, which would lead to the conclusion that cast-iron was made and applied in England 500 years ago:—"A curious specimen of the iron manufacture of the fourteenth century, and, as far as my own observation extends, the oldest existing article produced by our foundries, occurs in Burwash Church [Sussex]. It is a cast-iron slab, with an ornamental cross, and an inscription in relief. In the opinion of several eminent antiquaries, it may be regarded as unique for the style and period. The inscription is much injured by long exposure to the attrition of human feet. The letters are Longobardic, and the legend appears, on a careful examination, to be—

'ORATE P. ANNEMA JHONE COLINE (or COLINS).'

'Pray for the soul of Joan Collins.'

Of the identity of the individual thus commemorated I have been unable to glean any particulars. In all probability she was a member of the ancient Sussex family of Collins, subsequently seated at Socknersh, in the adjacent parish of Brightling, where, in company with many of the neighbouring gentry, they carried on the manufacture of iron, at a place still known as Socknersh Furnace." *

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stone seat, in others a fragment of a glass armlet, part of the horn of the red deer, and three bottom stones of handmills. The Celtic remains on Broughlow, Chesters, and Ingram Hill have also been examined. The most recent diggings have been made on Yeavering Bell. On the summit of the Bell, 1300 feet above the level of the sea, there is a rampart of masonry inclosing twelve acres; and within this, again, is a sunken chamber in which sacrifices are supposed to have been offered. This chamber was cleared of earth, leaving its masonry well defined; but no arrangement of a sacrificial character could be traced. On the slopes of the hill are several fortlets, or ramparts, surrounding hut-circles which have also been opened out. In one a small guard-chamber was found at the entrance recessed into the thickness of the wall of the rampart. Flint arrow-heads, broken pottery, querns, fragments of glass and oak were found in the soil in different places. The discovery also *of pieces of iron slag* furnishes a new view of Celtic life, as a general impression prevailed among antiquarians that the ancient Britons were unacquainted with the art of smelting."

* Op. cit. p. 97.

According to the same antiquarian, the first cannons of cast-iron were manufactured at Buxted [Bucksteed], in Sussex, by Ralph Hoge or Hogge, in 1543 (35 Henry VIII).[7] "This founder," it is stated, "employed as his assistant Peter Baude, a Frenchman, whom he had probably brought over to teach him the improved method." But, as Lower remarks, this connection was probably not of long continuance; for it is recorded that "John Johnson, covenant servant to the said P. Bawd [*sic*], succeeded and exceeded his master in this his art of casting ordnance, making them cleaner and to better perfection. And his son, Thomas Johnson, a special workman, in and before the year 1595 made 42 cast pieces of great ordnance of iron, for the Earl of Cumberland, weighing 6000 lbs., or three tons a-piece."[8] However, it is not certain whether Sussex was the scene of these operations.

Agricola, who was born in 1494 and died in 1555, appears to have been acquainted with cast-iron; for he thus writes: "Iron, smelted from iron-stone, is easily fusible, and can be tapped off. When the same, after the slag has been lifted off, is further heated to redness [*glüht*, which the German translator renders 'frischt'], it becomes malleable, and may be worked under the hammer and drawn out, but can no longer be easily poured, except when it is again melted down."[9] The last part of the sentence is somewhat obscure.

In the sixteenth century, the destruction of our forests by "voracious iron-works," as Evelyn designated them, had proceeded to so great an extent as to excite alarm on account of the increasing scarcity of wood, especially, it would seem, for naval purposes. Accordingly, an Act was passed in the first year of the reign of Elizabeth to the effect, "that no person or persons hereafter shall convert or employ, or cause to be converted or employed, to coal [*i.e.*, burn into charcoal] or other fuel, for the working of iron, any timber-tree or timber-trees of oak, beech, or ash, or of any part thereof, of the breadth of one foot square at the stub end, growing within fourteen miles of the sea, or of any part of the rivers of Thames, Severn, Wye, Humber, Dee, Tine, Teese, Trent, or any other river or creek or stream by which carriage is commonly used by boat or other vessel to any part of the sea, upon pain of forfeiture for every such tree or part thereof so employed or converted to coal or other fuel for the making of iron, as is aforesaid, forty shillings of lawful money of England; the one-half of all which forfeiture to be to our sovereign lady the Queen's Majesty and her heirs and successors, and the other money to him or them that will sue for the same by original writ, bill, plaint, or information, wherein no essoin, protection, injunction, or wager of law shall be admitted or allowed. Provided always, that this Act shall not extend to the county of Sussex, nor to the weald of Kent, nor to any of the parishes of Charlwood, Newdigate, and Leigh, in the weald of the county of Surrey."[1]

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[7] Op. cit. p. 104. On the authority of Holinshed, 2. p. 960.

[8] Ibid. p. 105. Cited by Lower, from Hayley's MSS., British Museum.

[9] Georg Agrikola's Mineralogische Schriften übersetzt von Ernst Lehmann. Freyberg, 1810. 3rd part, 2. p. 227.

[1] Some Account of the Worshipful

In 1584, being the 27th year of Elizabeth's reign, an Act was passed for the preservation of timber in Sussex, Surrey, and Kent. "This Act sets forth that whereas by over great negligence or number of iron works which have been and yet are in the wealds of the counties of Sussex, Surrey, or Kent, it is thought that the great quantity of timber which hath been grown in those parts hath been greatly spoiled and wasted, and in a short time will be utterly consumed, if some remedy be not provided. And then enacts, that no person, from and after the feast of Easter next, shall erect in any place within the said counties any manner of iron-mills, furnace, finary, or blomary,[2] for the working or making of iron or iron-metal, other than either upon such old and former bayes or pens whereupon hath lately been or at the time of the new erection shall be then standing some iron-mills, furnace, or hammer, or else in or upon such lands as the party so erecting any such new intended works shall continually furnish the same with a sufficient supply of wood standing and growing upon their own proper soil or land, being to him or them in fee simple, etc.; nor shall convert or employ to coals [charcoal] for the making of iron, etc., the bodies of any sound timber-trees apt for making good and sufficient cleft wares, or sawing-timber of oak, ash, or elm, of the breadth of one foot square at the stub or any part of the body; upon pain of forfeiture for every such iron-mill, etc., so erected the sum of three hundred pounds, and for every body of such tree, etc., forty shillings. Provided always, that the tops and offals of all such trees within the wealds of Sussex, Surrey, and Kent, the same not being within eighteen miles of London, or eight miles of the river Thames, or four miles of the towns of Rye and Winchelsea, or within three miles of Hastings, or within four miles of the hills called the Downs between Arundel and Pevensey, may be converted into coal for making of iron, etc."[3]

This is pretty sharp legislation, it must be admitted; and at the present time its equivalent would be severe restrictions on the working of coal, with a view to prevent its exhaustion, about which so much apprehension has of late been expressed. In the days of Queen Elizabeth the disforesting of the country had proceeded to such an extent as to excite reasonable alarm lest wood, then the only fuel in common use, should become exorbitantly dear, and the Maritime Power of England should suffer from want of suitable timber, wherewith to build those wooden walls which Evelyn,[4] even long afterwards, declared were, under God, the only protection of the nation, but which, in these days of armour-plated ships, are comparatively worthless lumber. But, apart from social and political considerations, in the minds of such men as Evelyn there was a deeply rooted dislike to the smelting and manufacture of iron. Thus, alluding to a fine oak, "call'd the Lady Oak," which "bore five foot square, forty foot long," and

Company of Ironmongers. Compiled from their own records and other authentic sources of information. By John Nicholl, F.S.A. 1851. Privately printed. p. 84.

[2] This seems to be the most correct way of spelling the word, which, as has been previously stated, is derived from "bloma."

[3] Some Account, etc. p. 118.

[4] Born 1620.

"contain'd twenty tun of timber," most of which "sold for 20s. per tun, besides that the boughs afforded twenty five loads of fuel-wood," Sir Ed. Harley said to Evelyn, "Is 't not pitty such goodly creatures should be devoted to Vulcane?" The reply was, "So far this noble gent., to which I would add 'Diræ,' a deep execration of iron-mills, and I had almost sayd iron-masters too."[5]

Evelyn states that in his time in Sussex alone, owing to the devastation caused by iron and glass-works, of the ancient Andradswald, originally "one entire wood," 120 miles long and 30 broad, "little or no sign" remained. "Certainly," he remarks, "the goodly rivers and forests of the other world would much better become our iron and saw mills than these exhausted countreys, and we prove gainers by the timely removal."

The time had now arrived when attention would necessarily be directed to the possibility of substituting pit-coal for charcoal, then termed coal, in the extraction of iron from its ores, and in the subsequent stages of its manufacture. Pit-coal had certainly been used as fuel for ordinary purposes so long ago as A.D. 853, as it is distinctly specified in a grant of lands of that date to the Abbey of Peterborough. In 1239 Henry the Third granted a charter to the townsmen of Newcastle-on-Tyne for liberty to dig coals, and this is stated to be the earliest notice extant of the actual working of coal. There is a document dated A.D. 1245, of the same reign, in which the expression "carbo maris," sea-coal, occurs, and by this it has continued to be designated nearly until the present day; in the same document express mention is made of coal-pits and of the wages of the colliers who worked in them. The use of coal in London and the suburbs was prohibited by royal proclamation of Edward the First, "to avoid the sulferous smoké and savour of the firing," smiths only being excepted; but in twenty years afterwards it was burned in the royal palace. Harrison, in his description of England, prefixed to Holinshed's Chronicle, edited in 1577, wrote the following sentence, which is especially apposite in this place:—"Of cole-mines we have such plenty in the north and western parts of our island as may suffice for all the realme of Englande. And soe must they doe hereafter indeede if wood be not better cherished than it is at present: and to say the truth, notwithstanding that very many of them are carried into other countryes of the maine, yet theyr greatest trade beginneth to growe from the forge into the kitchen and halle, as may appear already in most cities and townes that lye about the cost, where they have little other fewel except it be turfe and hassocks. I marvayle not a little that there is no trade of these into Sussex and Southamptonshire, for want whereof the smiths do work their yron with charre-coal. I think that farre carriage be the only cause, which is but a slender excuse to inforce us to carry them unto the mayne from hence."[6]

[5] Some Account, etc. p. 121. Quoted from Evelyn's Sylva. It is conjectured by some geologists that coal may exist in Sussex at workable depths; and should this conjecture prove correct, it is not improbable that iron-smelting may be resumed in that county, where plenty of iron-ore remains.

[6] I have extracted the preceding information concerning the history of coal

A patent, dated A.D. 1611, February 29, was granted by James the First during the term of 31 years to Simon Sturtevant for the use of "Sea-coale or Pit-coale" in various metallurgical and other manufacturing operations, the extraction and working of iron being specially mentioned. According to Sturtevant, there existed at that time in England and Wales "eight hundred milnes for the making of Iron," of which 400 were in Surrey, Kent, and Sussex, 200 in Wales, and 20 in Nottinghamshire, the remaining 180 being supposed to exist in other localities in England, Scotland, and Ireland. The same authority further states that "one milne alone spendeth yearly in char-coale 300 pound and more." By the substitution of pit-coal for charcoal in the iron-works alone, the saving is estimated at 320,000l. per annum. It does not appear that Sturtevant's alleged inventions with respect to iron were ever carried into practice; although he announces that "greene glass for windows is made as well by pit-coale at Winchester house in Southwarke," as in other places with wood, and smiths had during many years used "small sea-coal," which answered quite as well as charcoal. In his treatise, entitled 'Metallica,' which is in the form of a dialogue, he puts the question, "What meanes are to be used to make Earth-coale as serviceable for metalique purposes as wood or Char-coal?" The answer does not present any solution of the problem; but it suggests the probability that coking may have been intended, and purposely concealed. It is as follows:—"There are three sorts: the first is to bring earth coal to that equality of heat that wood or charcoale hath, that is to say, that it maketh neither hotter or coulder fire than wood or charcoale doth; the second meanes is, so to order and prepare pit-cole that all nocure [noxious] proprieties which are averse from all Metallique substances may be abstracted in it; the third meanes is, the addition and infusion of those deficient properties which, as they are in charcoal, so are they to be found in pit-coal." The 'Metallica' is full of pedantic conceits and ridiculous terminology.[8]

Sturtevant's patent was speedily "cancelled and made voyd, by reason of his standing outlawed at the time of the grant," and "his neglect and not performance of the workes;" and in 1613 his privileges were transferred to John Rovenzon, who had been instrumental in procuring the original patent. We are assured that Rovenzon "satisfactorily effected" what Sturtevant had promised, and failed to accomplish; but no evidence is advanced in proof of the fact. The new patentee was the author of 'A Treatise of Metallica,' though "not that which was published by Mr. Simon Sturtevant upon his Patent." Rovenzon seems to have invented "bloomeries, fineries, and chafferies of devision [*sic*]," in which "the material to be melted or

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from 'The History of Fossil Fuel, the Collieries, and Coal Trade of Great Britain.' 2nd ed. London, 1841. p. 305 et seq.

[7] Dud Dudley, in his treatise published 1665, states that Scotland made no iron.

[8] It has been reprinted by the Commissioners of Patents. The title is 'Metallica; or, The Treatise of Metallica. Briefly comprehending the Doctrine of diverse new Metallical Inventions, but especially how to Neale, Melt, and Worke all kinde of Mettle Oares, Irons, and Steeles, with Sea-Coale, Pit-Coale, Earth-Coal, and Brush Fewell.'

wrought may be kept divided from touch of the fewels;" and he clearly describes the reverberatory furnace. He concludes his little treatise with the announcement that, "Whereas an Iron-worke cannot be well set up and set on worke after the usuall manner without a 1000 pound or 1500 pound dis-bursement and stocke; now by this new Invention an 100 Stocke will performe as much with Sea-cole and the new-devised Furnaces, having a convenient house to set the Furnace In." The invention referred to was probably the application of the reverberatory furnace; for, writes Rovenzon, "the furnace being a winde furnace (which is best), saveth the charge of the bellowes, and of a milne to make them blow."[9]

After the failure of Sturtevant and Rovenzon, unsuccessful attempts to extract iron from its ores by means of pit-coal having been made by one Gombleton at Lambeth and Dr. Jorden of Bath, at length Dud Dudley, of Tipton, appeared on the scene; and to him is assigned the credit of having first solved this important economical problem. He was fourth natural son of Edward Lord Dudley by his concubine Elizabeth, daughter of William Tomlinson, of Dudley. He was born in 1599, and was buried in St. Helen's Church, Worcester, October 25, 1684. He married Elinor, daughter of Francis Heaton, of Groveley Hall, who was buried in the same church December 3rd, 1675. He appears to have died without issue. He was colonel in the army of Charles the First, and General of the Ordnance to Prince Maurice. On his monument, fixed to the south wall of St. Helen's Church, it is recorded that he was captured in 1648, condemned, but not beheaded.[1]

Dud Dudley published an account of his labours relating to the substitution of pit-coal for charcoal in the smelting of iron, but carefully refrained from disclosing his method. The title is as follows:— 'Dud Dudley's Metallum Martis: or Iron made with Pit-coale, Sea-cole, etc., and with the same Fuell to Melt and Fine Imperfect Mettals, and Refine perfect Mettals.' Lond. 1665, pp. 54.

In 1619 he was removed from Balliol College, Oxford, to superintend his father's iron-works at Pensnet in Worcestershire, consisting of one [blast] furnace and two forges, all working with charcoal. As wood had become scarce, and pit-coal abounded near the furnace, Dud Dudley was induced to make trial of this fuel as a substitute for charcoal. With this view, he informs us, he altered his furnace, and his first experiment was so successful that he "made iron to profit." The quality of the metal was found "to be good and profitable, but the quantity did not exceed above 3 Tuns *per* week." He immediately informed his father of his success, who thereupon applied to the king

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[9] Rovenzon's Treatise, dated 1613, has also been reprinted by the Commissioners of Patents. The name is also spelt Rovinson.

[1] His pedigree is extracted from the Herald's Visitation of the County of Stafford, made in the year 1663, and now in the College of Arms, London. His monumental inscription is given in Nash's Worcestershire, vol. ii., App. 149. I am indebted for all these particulars to Mr. John N. Bagnall, of Shenstone Moss, near Lichfield.

for a patent which was granted for 31 years.[2] In the year following the patent a disastrous flood occurred, called "the great *May-day Flood*," which "not onely ruinated the Authours Iron Works, and Inventions; but also many other mens Iron works." This event, Dudley tells us, brought joy to many iron-masters, whose works escaped, and who had disparaged his inventions, because he sold iron cheaper than they could afford it. These envious rivals even complained to the king that Dudley's iron was not merchantable, whereupon he was commanded to send samples of his bar-iron, suitable for military and naval purposes, to the Tower of London to be duly tested by competent persons. The result was favourable to Dudley, and we are informed, "that the iron-masters and iron-mongers were all silenced until the 21st of King *James*," when, at the Parliament of that date, all monopolies being declared null, an attempt was made by various iron-masters to apply the declaration to the invention of smelting iron with pit-coal and peat. However, Lord Dudley and Dud Dudley obtained an extension of the patent for the term of 14 years, after which the latter continued to produce annually a large quantity of good and merchantable iron, which he sold at 12*l*. per ton. He also manufactured all sorts of cast-iron wares, such as brewing cisterns, pots, and mortars, better and cheaper, it is alleged, than any previously made in this country with charcoal as fuel.

At length Dudley's opponents, the charcoal iron-masters, prevailed, and succeeded, wrongfully, in depriving him of his "works and inventions." But of the means by which this triumph was achieved, no account is given. Dudley afterwards erected a furnace at Himley, in Staffordshire, and there made much iron with pit-coal; but not possessing a forge, and being, therefore, unable to convert his pig-iron into bars, he was obliged to sell it to the charcoal iron-masters, "who did him much prejudice, not onely in detaining his stock, but also disparaging the iron; *Himly* Furnace being Rented out unto Charcole Iron-Masters." Dudley constructed another large furnace 27 ft. square, all of stone, at Hasco (now Askew) Bridge, in the parish of Sedgley, Staffordshire, and worked with larger bellows than ordinary. In this he produced weekly 7 tons of pig-iron, the greatest quantity ever made in Great Britain with pit-coal up to that period. But poor Dudley was again molested; a riot occurred, and the bellows of his new furnace were cut to pieces by riotous persons, so that, being wearied with law-suits and riots, he was disabled and prevented from carrying on his invention until the expiration of the term of his first patent. He was imprisoned, and, according to his own statement, wrongly, in the Compter in London for a debt of several thousand pounds. In the fourteenth year of the reign of Charles the First, in

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[2] There is some discrepancy as to dates. At p. 48 the invention is stated to have been made in 1618, that is a year before Dudley left Oxford, recorded at p. 5. Again, at p. 12, the patent is stated to have been granted in the 19th year of the reign of James I., whereas it was granted A.D. 1619 (p. 7), in the 17th year of that king, who ascended the throne in 1603.

spite of much opposition, he obtained the grant of a fresh patent for the use of pit-coal and peat, "not only for the making of Iron into cast-works and bars, but also for the Melting, Extracting, Refining, and Reducing of all Mines, Minerals, and Mettals," with pit-coal and peat. Dudley's troubles were not yet ended; for, having entered into partnership with two persons at Bristol and begun to erect a new furnace near that city in 1651, he became involved in litigation with his partners, who, he says, "not only cunningly drew me into Bond, entered upon my Stock and Work, unto this day detained it, but also did unjustly enter Staple Actions in *Bristow* of great value against me, because I was of the Kings Party; unto the great prejudice of my Inventions and Proceedings, my Pattent being then almost extinct; for which, and my Stock, am I forced to Sue them in Chancery."

Dudley relates the attempts of several persons to whom Cromwell and the Parliament granted a patent and an Act for making iron with pit-coal. Spacious wind-furnaces and pots of glass-house clay were tried in the Forest of Dean at great expense, but the results were signal failures. Dudley being importuned for advice visited the Forest, inspected the methods proposed, and pronounced that they could not be successful. A second patent was granted by Cromwell to Captain John Copley for the application of pit-coal to the smelting of iron, and attempts were made to conduct the operation at Bristol, but these also failed. In 1657, "all men now desisting from the Inventions of making Iron with Pit-cole and Sea-cole," and Dudley being moved with pity that no man was able to master the art, petitioned Charles the Second, the same day on which he landed, for a renewal of his patent, but met with a refusal, and then ceased from further prosecuting his invention.

Like many modern patentees, Dudley appears to have unduly extolled the merits of his invention; for he asserted that not only was pig-iron smelted with pit-coal cheaper, but "more excellent" than that smelted with charcoal. Dudley sold his pig-iron at 4*l.* per ton, and his bar-iron at 12*l.* per ton, the prices of charcoal pig-iron and charcoal bar-iron being at that time 6*l.* or even 7*l.* per ton, and from 15*l.* to 18*l.* per ton respectively. In no part of Dud Dudley's Treatise is there any hint as to the nature of his invention, which, probably, consisted in using coke instead of raw coal. I am informed that the only visible remains of his smelting operations are cinders at Askew Bridge.

After the cessation of Dud Dudley's labours in the smelting of iron with pit-coal, Plot informs us that efforts to accomplish that object with raw coal were again made in Staffordshire by one Blewstone, a high German, who built a furnace at Wednesbury "so ingeniously contrived that only the flame of the coal should come to the ore, with several other conveniences." This was probably a reverberatory furnace, and the experiment ended in failure.[3]

[3] The Natural History of Staffordshire. By Robert Plot, LL.D. Oxford, 1686. p. 128.

An interesting account of the iron-works of the Forest of Dean by Henry Powle, is contained in the Philosophical Transactions for [illegible].* Charcoal was then the only fuel used for smelting, and the author states that several ineffectual attempts had been made to employ sea-coal as a substitute, which [illegible] in the [illegible] would be easily given and was much more expensive than charcoal. The [illegible] found by experience, [illegible] a furnace [illegible] the most [illegible] parts of the ore and [illegible] much of the metal unmelted." The [illegible] were about [illegible] square in the middle, nearly [illegible] ft. high, and [illegible] ft. wide at the [illegible]. The blowing apparatus is described as follows:—"Behind the furnace are placed two large pair of bellows, whose noses meet at a little hole near the bottom. These are compressed together by certain [illegible] placed in the axis of a very large wheel, which is turned about by water in the manner of an overshot mill. As soon as these [illegible] are slid off, the bellows are raised again by the counterpoise of weights, whereby they are made to play alternately, the one giving its blast all the time the other is rising." The pig-iron produced, it is stated, was converted into malleable iron in a finery, described as an "open hearth," with charcoal as the fuel. Re-heating was effected in an open hearth, called the chafery, in which charcoal was also used.

A considerable period appears now to have elapsed before any further attempt was made to smelt iron with pit-coal; and it was reserved for Abraham Darby to solve the problem with complete success at the Colebrook Dale Iron-works, Shropshire, about the year 17[illegible]. It was at the same works that his father Abraham had introduced the art of casting iron, for which they have ever since been renowned. So far as I am aware, there is no name which has been so long and so honourably known in connection with the iron trade of this country as that of Darby. Conceiving, therefore, that a sketch of the history of the family would be acceptable to the readers of this volume, and not having met with any trustworthy published details on the subject, I applied to the existing representative of the family, Mr. Abraham Darby, of the Ebbw Vale Iron-works, for assistance, when Mrs. Darby, at the request of her husband, immediately responded to my application. I now present with much pleasure the following interesting narrative, which that lady has compiled with great care from authentic records, omitting only certain genealogical details which have no special bearing upon the connection of the family with the smelting and manufacture of iron.

About the time of the Battle of Worcester (Sept. 3, 1651), the furnace for smelting iron ore at Colebrook Dale belonged to one of the family of Wolffe, of Madeley, the same Wolffe who, after the battle, sheltered the royal fugitive in a barn, while the soldiers on the King's track were regaled by Mrs. Wolffe with bread, cheese, and ale. The furnace passed next into the hands of a Mr. Fox, who made cannon-balls and hand grenades for the Government. It was blown up by

* 11. p. 981.

the bursting of the Pool Dam, the water gaining access into the interior. Fox went to Russia with Peter the Great, and was heard of no more.

About the year 1670 John Darby occupied the farm called the Wren's Nest, near Dudley, in Worcestershire. He married in 1675, and had a son, named Abraham, born in 1677, who was apprenticed to a malt-mill maker in Birmingham. In 1698, at the expiration of his apprenticeship, he married Mary Sargeant, of Birmingham, and began business as a malt-mill maker on his own account at Bristol. About six years afterwards he sailed to Holland, and engaged Dutch brass-founders to return with him to England. In 1706, in conjunction with four partners, he established at Bristol the brass-works known as Baptist Mills, of which he took the management. He conceived the idea that cast-iron might be substituted for brass, and prevailed upon his Dutch workmen to try to make iron castings in moulds of sand; but they failed, and considerable loss was incurred in their experiments.

At this time a Welsh shepherd-boy, named John Thomas, succeeded in rescuing a flock of his master's sheep from a snow-drift; and later in the spring of the same year, during heavy rain and the melting of the snow, he swam a river to fetch home a herd of mountain cattle. These he collected and drove to the river, but the ford had now become a boiling torrent. He nevertheless crossed it on the back of an ox, and brought home the whole herd in safety. As a reward for his courage, his master presented him with four of the sheep which he had saved. He sold their wool in order to buy better clothing for himself, and afterwards disposed of the sheep, so that he might obtain money wherewith to travel to Bristol and "seek his fortune." Afraid of being pressed for a soldier if found in Bristol out of place, as it was then the time of the Duke of Marlborough's wars, he requested his master to recommend him as an apprentice to a relative, who was one of the partners of the Baptist Mills. The boy was accordingly sent into the Brass-works, until he should procure employment. As he was looking on during the trials of the Dutch workmen to cast iron, he said to Abraham Darby that he "thought he saw how they had missed it." He begged to be allowed to try, and he and Abraham Darby remained alone in the workshop the same night for the purpose. Before morning they had cast an iron pot. The boy Thomas entered into an agreement to serve Abraham Darby and keep the secret. He was enticed by the offer of double wages to leave his master; but he continued nobly faithful, and afterwards showed his fidelity to his master's widow and children in their evil days. From 1709 to 1828 the family of Thomas were confidential and much-valued agents to the descendants of Abraham Darby. For more than 100 years after the night in which Thomas and his master made their successful experiment of producing an iron casting in a mould of fine sand, with its two wooden frames and its air-holes, the same process was practised and kept secret at Colebrook Dale, with plugged key-holes and barred doors.

The sleeping partners at Baptist Mills became dissatisfied with Darby, believing that he had lost his judgment, and was wasting money in fruitless experiments. The partnership was, consequently, dissolved, and Darby drew out his share of the capital. He took a lease of the furnace at Colebrook Dale, and removed with his family to Madeley Court in 1709, John Thomas accompanying him. In the picturesque valley of Colebrook Dale, the rivulet, called in old records "Coldbrook," winds between rocky hills from the spurs of the Wrekin above Lum Hole, till it falls into the Severn more than a mile below. The site was well adapted for iron-making: there was available water-power; iron ore and limestone occurred in the locality, and the neighbouring copse-covered hills supplied an abundance of charcoal. Abraham Darby built another furnace, or, as he termed it, "forge," and took leases of minerals, and his trade increased. In 1715 he sold one share, *i.e.*, $\frac{1}{16}$ part, of the works for 330*l.*, which in 1758 was bought back for 1150*l.* He died March 8, 1717, aged 40, leaving a widow and two sons, of whom the eldest, named Abraham, was born March 12, 1711.

While Abraham Darby lived, affairs prospered; but, unhappily, after his decease, a brother-in-law in whom he had confided acted dishonestly towards the widow and family, and even defrauded some of the workmen.

Young Abraham Darby entered upon the management of the Colebrook Dale Iron-works about 1730. As the supply of charcoal was fast failing, Abraham Darby attempted to smelt with a mixture of raw coal and charcoal, but did not succeed. Between 1730 and 1735 he determined to treat pit-coal as his charcoal-burners treated wood. He built a fire-proof hearth in the open air, piled upon it a circular mound of coal, and covered it with clay and cinders, leaving access to just sufficient air to maintain slow combustion. Having thus made a good stock of coke, he proceeded to experiment upon it as a substitute for charcoal. He himself watched the filling of his furnace during six days and nights, having no regular sleep, and taking his meals at the furnace top. On the sixth evening, after many disappointments, the experiment succeeded, and the iron ran out well.[5] He then fell asleep in the bridge-house at the top of his old-fashioned furnace so soundly that his men could not wake him, and carried him sleeping to his house, a quarter of a mile distant. From that time his success was rapid. To increase the power of his water-wheels of 24 ft. diameter, he set up a "fire-engine" (*i.e.*, an old atmospheric steam engine), to raise water from under the lowest and send it to the upper pond, which supplied water to the works, and put in motion the largest bellows that had been made. He obtained additional leases of valuable minerals, and erected seven furnaces, with five fire-engines. In 1754 the first furnace at Horsehay was blown in. In December, 1756, "Horse-

[5] According to Scrivenor, "pit coal was first used by Mr. Abraham Darby in his furnace at Colebrook Dale, in 1713" (History of the Iron Trade. New ed. 1854, p. 56); but this statement is certainly erroneous.

hay's work" was declared to be "at a top pinnacle of prosperity, 20 and 22 tons per week, and sold off as fast as made, at profit enough." Iron rails were laid down for the tram-waggons between Horsehay and Colebrook Dale about this time. Abraham Darby died March 31, 1763, aged 52. He is described as small, of slight build, yet strong and active, with very bright black eyes.[6]

The eldest son, still named Abraham, was born April 24, 1750. He took the charge of the Colebrook Dale Works when he was not quite 18 years of age. In 1788 he received the gold medal of the Society of Arts for his bridge over the Severn, the first ever constructed of cast-iron. He died March 20, 1791, aged 41.

The management of the works soon devolved upon Edmund Darby, son of a younger brother, born April, 1782. He died suddenly March 29, 1810. Under his direction the rolling-mill at Horsehay was erected, and the old fire-engines replaced by the improved steam-engines of Boulton and Watt. He left two sons, Abraham and Alfred, who jointly took the management of the Colebrook Dale Works in 1830. Mr. Alfred Darby died suddenly April, 1852; Mr. Abraham Darby retired from the management of those works in 1851, and resided at Stoke Court until 1862, when he assumed the active management of the Ebbw Vale Iron Company's Works, of which he is a principal partner.

The substitution of pit-coal or coke for charcoal in the smelting of iron involved the necessity of increasing the pressure of the blast, and accordingly blowing machines, more powerful than bellows, were speedily introduced. It is stated that blowing cylinders were first used at the Carron Iron-works, established by Dr. Roebuck in 1760.[7] There were four single-acting cylinders of cast-iron, 4 ft. 6 in. in diameter; and the pistons, of which the stroke was 4 ft. 6 in., were worked in alternation, so that a continuous and tolerably equable blast was maintained. Greater uniformity in the pressure of the blast was afterwards secured by first blowing into capacious vessels or chambers, termed regulators, from which the air passed into the furnace. Double-acting cylinders followed in the natural course of improvement, and are now in general use. At the Dowlais Iron-works is a blowing cylinder 144 in. in diameter, with a stroke of 12 ft., making 20 double strokes per minute, the pressure of the blast being 3½ lbs. per square inch. The discharge pipe is 5 ft. in diameter and 140 yards long, thus answering the purpose of a regulator. The steam cylinder is 55 in. in diameter, the stroke 13 ft., the pressure of the steam 60 lbs. per square inch, and the engine works up to 650 horse-power.[8] I am not aware whether a

[6] In the Philosophical Transactions for 1747 is a short notice, in which it is stated that Mr. Ford made Iron at Colebrookdale brittle or tough, as he pleased; and cast cannon so soft as to bear turning like wrought iron. Ford (Richard) was a clerk in the Colebrook Dale Iron-works, who married Abraham Darby's eldest daughter, Mary, Aug. 1, 1718. After the death of Abraham Darby in 1717, Ford bought a share in the Iron-works at Colebrookdale. He was unsuccessful in business.

[7] History of the Iron Trade. Scrivenor, 1854. p. 83.

[8] Proceedings of the Institution of Mechanical Engineers, June, 1857. p. 112.

larger blowing cylinder than that above described has been constructed.

The history of the improvements in the smelting and manufacture of iron and steel, which succeeded the application of pit-coal, has already been presented under the heads of Puddling, Hot-Blast, Utilization of the Waste Gas of the Blast-Furnace, Cast-Steel, and the Bessemer Process. Great improvements yet remain to be effected, and one of the most urgently needed is a method whereby either the process of puddling may be superseded, or the labour now required to conduct it may be greatly reduced. I am not acquainted with any manufacturing operation which demands such severe muscular exertion in equally trying conditions. It is not surprising that puddlers should manifest a growing disinclination to bring up their children to this occupation, to which, as a general rule, their strength ceases to be equal beyond the age of 45 or 50. The Bessemer process, it was hoped, would cause the extinction of puddling; but this hope, as we have seen, has for the present at least been sadly disappointed.

Notwithstanding the marvellous development of the Iron trade in this and other countries since the introduction of railways, yet it may be safely affirmed that the uses of iron will be vastly more extended than at present, and that there is no just ground for apprehension lest there should be over-production of this precious metal. Even the railway system is in a state of rapid growth, and the time will come when every habitable part of the earth's surface will be reticulated with iron- or steel-roads. The day of Steel has arrived—but not to the exclusion either of wrought or cast-iron; and steel is destined to exercise an important influence on the destinies of the human race. Every rail, or at least the head of every rail, will be made of steel, as may be certainly inferred from the fact that steel rails have, under equal conditions, been proved to last eight times as long as wrought-iron rails, while the difference in prime cost between steel and wrought-iron rails is not at all proportionate to this difference in durability.

We have ample supplies of iron-ore; and happily, during the last few years, very extensive deposits of ore have been discovered in our liassic and oölitic beds in Yorkshire, Northamptonshire, and Lincolnshire. Our coal, however, is not only being consumed at a prodigious rate at home, but is being largely exported; and the question as to the probable duration of our coal-fields has of late been discussed with reasonable anxiety. In 1862 we raised 84,000,000 tons of coal, and the demand continually increases. Hitherto, owing to the abundance of our mineral fuel, we have been—and we still are—comparatively regardless of economy in its consumption. The time has now arrived when necessity will compel us to act differently, both in our manufactories and in our households.

APPENDIX.

Method of determining the quantity of combined Carbon in Iron and Steel. By Professor Eggertz, of Fahlun (Stockholm, 1862).[1]

When white pig-iron is dissolved in iodine with certain precautions a residue is left, containing carbon, silica, etc. From several results obtained by Eggertz from many varieties of white pig-iron and hard steel, this carbon-residue was found to be uniform in composition, and to contain on the average 59 % of carbon. Some of this residue, from white pig-iron free from graphite, has been analysed by Mr. T. L. Ekman, and after deducting the silica found to have the following average composition :—

Carbon	59·69
Iodine	16·07
Water	22·50
Nitrogen	0·13
Sulphur	0·23
Loss	1·38
	100·00

The quantity of carbon from four experiments varied 0·5 %. The proportion of carbon in the residue may be taken at 60 %. No alteration in weight occurs when it is heated from 95° to 110° C.; at 150° it loses 9 %, and at 240° about 33 %.

The process is conducted in the following manner :—

1 gramme (= 15·432 grs.) of iron, which has passed through holes of 0·2 of a line in diameter, is added in small portions to 5 grms. (= 77·16 grs.) of iodine and 5 cubic centimetres (= 0·18 fluid oz.) of water, contained in a glass vessel having a watch-glass cover, and previously cooled in ice-water. It is kept for 24 hours at a temperature of 0° C.: during the first 6 hours it should be carefully stirred with a glass rod, and afterwards less frequently; with these precautions it is possible to conduct the operation without the least evolution of hydro-carbons. The insoluble residue of carbon, silica, etc., is collected on a weighed filter, and washed with hot water until it becomes white or the filtrate is free from iron; or the residue may be washed with a solution of 2 parts of water and 1 part of hydrochloric acid, heated to 70° or 80° C., and finally with water. The filter and residue are dried at 95° to 100° C., until the weight remains constant; they are

[1] For translations from this and the two following papers, which are in Swedish, I am indebted to my friend Mr. Sandberg; and the abstracts of these papers here presented have been prepared by Mr. R. Smith.

afterwards ignited, and the weight of the silica, etc., is deducted. The loss by ignition represents the amount of carbon-residue, containing 60% of carbon; from these data the amount of carbon contained in the iron experimented on is found by calculation. When graphitic carbon is likewise present, it must be estimated in the usual way, and the weight deducted from the carbon-residue.

Example:—Mottled pig-iron has been found to contain 1·25% of graphite. By dissolving the iron in iodine it gave 5·5% of carbon-residue containing graphite. 1·25% deducted from 5·5% leaves 4·25% of carbon-residue, containing 60% of carbon, which is equal to 2·55% of combined carbon in the pig-iron under examination.

Method of determining combined Carbon in Pig-iron or Steel by a Colouration-test. By Professor Eggertz.

Sesquioxide of iron dissolved in nitric acid, if not too concentrated, yields a solution which is free from colour, or has only a feeble greenish tint. When pig-iron or steel is acted on by nitric acid, the solution is coloured by the carbon product in proportion to the amount of combined carbon present, and there is no action on the graphite. A normal solution is prepared by dissolving some cast-steel containing a known amount of carbon, with certain precautions to be described, in so much nitric acid of 1·2 specific gravity, that every cubic centimetre (= 0·037 fluid oz.) of the solution may represent 0·001 grm. (= 0·015 gr.) of carbon. This normal solution does not maintain its colour, but generally becomes paler after 24 hours. Feebly burnt sugar gives a yellow, and hard burnt sugar a brown, solution; by dissolving a mixture of the two in a solution of equal parts of water and alcohol, it is possible to obtain a yellow-brown normal solution of the proper tint, which may be kept for some time in a hermetically-sealed tube pretty well protected from the influence of light. In order occasionally to control the normal solution, 0·1 grm. (= 1·543 gr.) of steel containing a known weight of carbon is dissolved in 5 cubic centimetres (= 0·18 fluid oz.) of nitric acid, and the solution diluted until the tint corresponds to that of the normal solution of burnt sugar.

The process is conducted as follows: 0·1 grm. (= 1·543 gr.) of the finely divided iron or steel is put into nitric acid of 1·2 specific gravity, and free from chlorine, contained in a test tube of about 4 inches in length and 0·4 inch diameter. The test tube is immersed in water, and kept at a temperature of 80° C. If the temperature exceeds this, the colour of the solution decreases and shows too small an amount of carbon. By a lower temperature the dissolving proceeds too slowly, and the colour of the liquid may be too strong.

When the evolution of carbonic acid gas ceases, which for steel usually requires two or three hours, the test tube is removed and left to cool. The solution is then carefully decanted off from any black particles which may have been deposited during cooling into a graduated tube. A few drops of nitric acid are added, and heat ap-

plied: if no evolution of gas occurs, the black particles consist of graphite or slag; if otherwise, the test tube is cooled and the solution is added to that before obtained, and the whole diluted with water until the colour corresponds to that of the normal solution.

If 1 cubic centimetre of the normal solution correspond to 0·1 % of carbon, and the solution in the graduated tube measures 7 cubic centimetres, then the iron or steel operated upon contains 0·7 % of carbon.

As it is usually difficult to dissolve 0·1 grm. (= 1·543 gr.) of iron in less than 1·5 cubic centimetres of nitric acid, it is not possible with the before-mentioned normal solution to determine less than 0·15 % of carbon. When the carbon exceeds 0·5 %, the solution has a greenish tint, which causes some little difficulty in comparing it with the normal solution; in such a case, a poorer normal solution is made by adding 6 parts by measure of water to 3 parts of the common normal solution. If the quantity of carbon is large, as in white pig-iron, only 0·05 grm. (0·74 gr.) is to be employed.

In several iron-works in Sweden where the Bessemer process is practised, this method for determining the carbon has already been adopted, and has afforded much facility and certainty in the assortment of the steel, which before it was necessary to ascertain experimentally by forging and hardening.

Estimation of Phosphorus in Wrought-iron, Pig-iron, Steel, and Iron-ores. By Professor Eggertz

The iron or steel is reduced to powder and passed through a sieve with holes of about 0·2 of a line in diameter. 1 grm. of the iron or steel is gradually put into a small glass vessel covered with a watch-glass, and containing 12 cubic centimetres (0·43 fluid oz.) of nitric acid of 1·20 specific gravity. Heat is applied by a water-bath, and when the metal is dissolved, the glass plate is removed, the solution evaporated to dryness, the residue moistened with 2 cubic centimetres (0·075 fluid oz.) of nitric acid, and the same quantity of hydrochloric acid, and left for about one hour. Four cubic centimetres (0·15 fluid oz.) of water are then added, and the solution filtered. The filtrate and wash-water should not measure more than from 5 to 20 cubic centimetres (0·18 to 0·71 fluid oz.).

Not less than 2 cubic centimetres (= 0·075 fluid oz.) of the prepared solution of molybdate of ammonia are then added to the iron solution for every 0·001 grm. (= 0·015 gr.) of phosphorus supposed to be present in the iron or steel, and digested for three hours, with occasional stirring at about 40° C. If no precipitate be formed after the lapse of one hour, more solution of molybdate of ammonia is added. The yellow crystalline precipitate is collected on a weighed filter, washed with water containing 1% of nitric acid, and dried in a water-bath until the weight remains constant. The filtrate should afterwards be tested to see that no further precipitate is produced by the addition of the solution of molybdate of ammonia. The yellow precipitate contains 1·63% of phosphorus. If the amount of phosphorus present is

large, a less quantity of iron may be taken. A large number of estimations has been made in Sweden by this method on the same kind of iron, with only 0·01% variation in the amount of phosphorus present. For the estimation of phosphorus in iron ore 1 grm. (15·432 grs.) of the finely powdered ore is heated with 6 cubic centimetres (= 0·21 fluid oz.) of nitric acid, and the same quantity of hydrochloric acid, and the process conducted as before. Sometimes a known weight of the ore is treated as for an iron-assay, and the phosphorus estimated in the button of pig-iron obtained.

The estimation of the phosphorus can also be made by measuring the volume of the yellow precipitate obtained. The precipitate is brought into a funnel-shaped glass tube, compressed with a steel wire, measured by means of a small ivory graduated rule, and the amount of phosphorus found by calculation. The yellow salt contains—

Molybdic acid	91·69
Phosphoric acid	3·72
Ammonia	3·41
Water	1·18
	100·00

The solution of molybdate of ammonia employed may be prepared by calcining finely powdered sulphide of molybdenum at a low temperature, with occasional stirring. The molybdic acid thus formed is dissolved in strong ammonia, the insoluble residue separated by filtration, the filtrate evaporated to dryness, exposed to a red heat, and stirred until the dark blue colour becomes yellow or nearly white when cold; it usually contains a little B-phosphoric acid, and must be heated with nitric acid over a water-bath for three or four days in order to obtain C-phosphoric acid, and afterwards evaporated to dryness. This molybdic acid is digested in a closed bottle with ammonia of 0·95 specific gravity at 16° C. Four parts by weight of ammonia are added for one part of molybdic acid, the solution filtered, and suddenly added to 15 parts of nitric acid of 1·20 specific gravity, at 16° C. The solution is commonly of a yellow colour, a small quantity of yellow precipitate is soon formed, which contains C-phosphoric acid, and the solution is colourless. One cubic centimetre (= 0·037 fluid oz.) of this solution contains 0·06 grm. (= 0·924 gr.) of molybdic acid. Heated during 6 hours at 40° C., no white precipitate of molybdic acid is formed, but this occurs quickly when it is exposed to a greater heat, unless more nitric acid be added.

TESTING FOR SULPHUR IN PIG-IRON. By Professor EGGERTZ.

0·1 grm. (= 1·543 gr.) of the finely-divided pig-iron is placed in a tubular glass bottle, into which have been previously poured 1 grm. of water and 0·5 grm. or 15 drops of strong sulphuric acid. A small, clean, bright, metallic plate is suspended in the upper part of the interior of the bottle by means of a fine silver or platinum wire, and

held firmly by inserting the glass stopper. The bottle is left for about 15 minutes at the ordinary temperature, and the metallic plate is then removed.

If the pig-iron contain sulphur, the metallic plate is discoloured by the sulphuretted hydrogen gas evolved by the action of the sulphuric acid on the pig-iron, the colour varying according to the quantity of sulphur present from straw-yellow to pinchbeck-brown, bluish-brown, or blue; or, as it often happens, the metallic plate is unequally coloured, one colour predominating: for example, two-thirds of the surface may be pinchbeck-brown, and one-third bluish-brown. By comparing the colour of the metallic plate resulting from the experiment with a scale of colours obtained by experimenting on pig-irons containing known quantities of sulphur, the amount of sulphur present in the pig-iron is found. If the metallic plate is coloured blue, the bar-iron by the "frisch" process will be red-short; but if the colour is only brown, the bar-iron may nevertheless be red-short, and in this case the red-shortness will depend on other matters present besides sulphur.

The tubular glass bottle used is about 6 in. high, and 1 in. in diameter. The metallic plate is about $\frac{3}{4}$ of an inch long, $\frac{5}{16}$ of an inch broad, and $\frac{1}{16}$ of an inch thick, with a small hole at one end. It is composed of 75 parts by weight of silver and 25 parts of copper, or the same alloy as that employed for the Swedish Rigsdaler (Rixdollar). For use it is cleaned bright by means of a piece of soft leather and fine polishing powder, and dried between clean blotting paper, whereby all contact with the fingers is avoided. This method of testing will generally be found too sensitive for English irons, which contain a much larger quantity of sulphur than the Swedish.

Regulus obtained in smelting Iron-ore containing Sulphate of Baryta. Note by Mr. R. Smith.

The lustre is feebly metallic, fracture granular, colour bronzy, dark-grey, and black when powdered. It becomes oxidized on the surface by exposure to the air. Hydrochloric acid decomposes it with evolution of sulphuretted hydrogen, leaving 0·88 % of insoluble residue, consisting of sulphate of baryta. It was found to contain 43·91 % of iron (which is equal to 69·10 % of FeS), 16·36 % of barium (which is equal to 20·28 % of BaS), with small quantities of calcium, magnesium, potassium, sodium, manganese, and 0·08 % of copper. Phosphorus was absent.

Sulphur in Coke. Note by Dr. David S. Price.

The following are estimations of sulphur in some varieties of coke:—

From an inspection of many analyses I find that cokes are met with containing from 0·3 to 4·5 % of sulphur, and from 3 to 20 % of ash, although I know of only two varieties that contain as small a

quantity as [illegible] % of sulphur—half per cent. being about the average amount found in the best makes.

When at the Brymbo Iron-works some time since I had an opportunity of seeing Edwards's coal-washing machine in operation. The slack that was being washed was exceedingly "dirty." Mr. Darby gave me a sample of the coke made from it after washing. This I have since analysed, and find it to contain sulphur [illegible]·53, and ash 4·4 %—a result that must be considered highly satisfactory.

Coke made from "Wall" and "Bench" coal, near Ruabon, contained of sulphur 0·[illegible] %, and of ash 5·7 %.

Coke from "Wall," "Yard," and "Bench" coal washed—by what machine not stated—at Ruabon, contained of sulphur 0·61 %, and of ash 4·5 %; this would be from a slack coal, most likely.

Sample of best Durham coke contained of sulphur 0·82 %, and of ash 5·4 %.

The above four samples are "oven-cokes."

Sample of coke made by the Lilleshall Iron Company, Shropshire, and used in their blast-furnaces, contained of sulphur 0·515 %, and of ash 6·8 %.

Coke from Iron-works, Aberdare district, S. Wales, contained of sulphur 0·63 %, and of ash 3·70 %.

The last two are "yard-cokes."

On the Mode and Cost of Making Iron in South Wales about the year 1750.

For the following interesting historical notice I am indebted to Mr. Octavius Morgan. It is extracted from an old memorandum book in his possession.

An Account of making Cast or Pig Iron (wch are the same) in Great Britain, and more particularly in Monmouthshire and Breconshire: in a Dialogue between A. and B.

"*A.* Sir, you have often promis'd me to give me an account of the whole process of making of Pig Iron in Monmouthshire.

"*B.* I am ready to answer any questions you shall ask abt that matter, wch method in my opinion will be the best and easiest of informing you.

"*A.* I desire to know first then of what Iron is made?

"*B.* It is made out of Myne or Iron Oar.

"*A.* Where and in what sort of ground is this sort of Oar found?

"*B.* It is generally found in poor wet ground, on sides of Hills, and often lies near Coal.

"*A.* How deep does it usually lye under the ground?

"*B.* We seldome dig above three fathoms or eighteen foot deep for it, and our Miners are of opinion there is no Quantity deeper under the Earth in our Country.

"*A.* Are there several sorts of Oar?

"*B.* Yes, but we generally divide them into two sorts: the one we call Vein Oar, the other Pin Oar.

"*A.* Do these two sorts lye differently in the ground?

"*B.* Yes: the Vein Myne lies like a Pavement of Brick, and is sometimes two Inches thick, and from two to Seven, which is the thickest we have, and generally lies nearest the bottom of the Pitt or Trench.

"*A.* How does the Pin Myne lye?

"*B.* That lies more uncertain, but about the same Depth; but lies in lumps or parcells, sometimes a Tun or half a Tun in a Lump, or 4 or 5 hundred in some parcells.

"*A.* Is there any difference in the Colour of Oar or Myne?

"*B.* Yes: the Vein myne is generally of a pale yellowish colour, but the Pin myne is various, as a deep brown, blewish, and sometimes of a yellow colour.

"*A.* Is there any difference in the Weight or richness?

"*B.* The Pin myne is usually the weightiest and the richest.

"*A.* Pray what method do you use to get the Oar out of the ground?

"*B.* We have two ways: the one by digging a shaft in the ground, as is done for Coal or Lead; the other by scouring.

"*A.* What do you mean by scouring?

"*B.* That ought to be explained, because I think we are the only Country that get Oar that way, and we get almost all we use in that manner. It is done in this manner:—On the wash or enclosd ground on the sides of the Hills where we find Oar we digg a Trench about four or five foot wide till we come down to the Lowest Vein, about 14 foot deep, and in that Depth is usually 4 Veins or Layers of Oar. Then we make small ponds to hold rain Water, or any that comes out of Springs above the Trench that is cut; and as fast as the Ponds fill we let them down through a Floodgate into the Trench, which carries away all the Loose Earth, and leaves the myne behind and the lowest Vein bare. Then they undermine the Banks of the Trench on both sides, and when great quantities of the Banks are fallen down they let down the water out of the ponds again, which washes away all the Earth from the myne.

"*A.* What quantity of myne goes to make a Tun of Iron?

"*B.* About three Tun of Oar will produce a Tun of Iron, of Vein Oar, but less of Pin; but being mixed, that is the usual quantity.

"*A.* What price do you give for raising a Tun of Oar?

"*B.* For the Vein Myne usually ℘ Tun 0*l.* 1*s.* 8*d.*

"*A.* What do you give for the Carriage of it to the Furnace?

"*B.* We give from 3*s.* to 7*s.* ℘ Tun; so put it as a medium 5*s.* carriage.

"*A.* How do you Carry it?

"*B.* On Horses' backs, in small bags.

"*A.* How much will a Horse Carry?

"*B.* Two Hundred and a Quarter.

"*A.* What will as much as will make a Tun of Iron Cost delivered at the Furnace?—N.B. 28 horse Load is three Tun.

"*B.* Three Tun Raising Costs 5*s.*, the Carriage of 3 Tun will cost 15*s.*

"*A.* Pray do you use anything else besides the Oar?

"*B.* Yes: we use Lime Stone a tenth part, whch will Cost at the Furnace as much as will make a Tun of Iron 1*s.* 3*d.*

"*A.* What Fewel do you use to melt the Oar and Limestone?

"*B.* Charcoal made of Wood is the only Fewel we use.

"*A.* Pray how much Charcoal will make a Tun of Iron?

"*B.* We use now abt 18 Sacks (a sack is a horse load), and shoud contain eight bushel (a measure we have so called at the Furnace): two of these sacks go to burn or Calcine the mine before tis us'd in the Furnace, but in most places they use more.

"*A.* Pray what is the Charge of such a quantity of Charcoal?

"*B.* I will inform you in as plain a method as I can from the begins to the end of the vast charge. We buy our Wood by the short Cord, and a Cord wth us Contains 9 foot long, 4 foot 6 Inches high, and 2 foot 2 inches in the billet (but in other Countys it is abt an 8th part less). Now for the price at this time, it is at 3*s.* 6*d.* ℘ Cord, and four Cord will make a load of Coal, whch is twelve sacks so much; 14 shillings: besides we pay for the Cutting.

"*A.* Pray what does the Cutting Cost?

"*B.* We Cut by the short Cord at 1*s.* 6*d.* ℘ Cord; so Cutting as much wood as will make a load of Coal will cost 6*s.* There is another Charge, which is Cording the wood, or laying it up in close ranks.

"*A.* What does that Cost?

"*B.* Abt 3*d.* ℘ Cord, wch makes 1 shilling.

"*A.* Pray what is the next charge?

"*B.* It is Coaling the wood, or converting it into Charcoal, wch is done by colliers, who cover the wood wth Turf and Earth, and then fire it underneath; and there it lies smothering for abt 12 days, and then becomes Charcoal.

"*A.* Pray what price have the Colliers?

"*B.* The general price is 4*s.* a Load, or twelve sacks; but there are Hurdles made of boughs and sacks, &c. come to 1 shilling more, so in all 5*s.* ℘ Load.

"*A.* What's the next Charge?

"*B.* Carrying the Coal to the Furnace. We carry a great way of late, wch makes that charge very uncertain, from 1 mile to 15; so put it at a medium at 8*s.* ℘ Load.

"The expence total for Charcoal is as follows by adding the charge together:—

	£.	s.	d.
For 4 Cord of Wood	0	14	0
For Cutting	0	6	0
For Cording	0	1	0
For Coaling	0	5	0
For Carriage	0	8	0
Total	1	14	0

" *A.* I desire to know what further Charge you are at.

" *B.* The next charge is the Workmens Wages, and I take the best way of reckoning, that is by the Tuns of Iron made. I believe wth the Clerks, Stocktakers, Mine breakers Included, we may reckon it at 5*s.* ℘ Tun.

" *A.* Is there no charge for Repaires?

" *B.* Yes: that is called Incidents, as making a new hearth, Leathering the Bellows, and new Wheels, etc.

" *A.* Pray how do you Compute that charge?

" *B.* The way of doing that is by the Quantity of Iron usually made at the Work. We make 800 or more in two year, Lying by one year to get Stock together, and make 800 Tun as a Blast the next year, w^{ch} at 2*s.* ℘ Tun makes 80*l.*, and that will pay all Incidents.

" *A.* I suppose this is all the Charge.

" *B.* There is still another, w^{ch} is Rent of Work, the Interest of Stock. The Furnace is worth 50*l.* ℘ annum, and required 3000*l.* Stock, the Interest of w^{ch} for two year and rent of the Furnace is 400*l.*, w^{ch} will amount in eight hundred to 10*s.* ℘ Tun.

" *A.* If this is all, I desire to know the Sum Total.

" *B.*

	£.	s.	d.
Imprimis the Myne	1	1	3
Limestone	0	1	3
The Charcoal	2	10	0
Workmen and Clerk's Wages	0	5	0
Incidents, as hearths and bellows	0	2	6
Rent of y^{e} Work, Interest of Stock	0	10	0
Total	4	10	0

" I think this estimate is too high.

" *A.* I have but one Question more to ask: what is a Tun of Iron worth?

" *B.* At this time tis worth 6*l.* 10*s.*

" *A.* How much do you make a Week?

" *B.* At a Medium 24 Tun, but at this time something more."

Dimensions of Bellows.—For Finery 6 ft. 10 in. long, width 2 ft. 5 in., tapered to 10 in. and 4 in. thick. For Chafery 9 ft. 9 in. long, width 2 ft. 10 in., tapered to 13 in. and 5 in. thick.

Cast-iron Columns and Girders in Fires.

In the construction of the German Bazaar, Langham Place, which was burnt down last year, columns and girders of cast-iron had been employed; and of these many were singularly bent and distorted by the effect of the conflagration. The girders were 18 ft. long and 13 in. deep in the middle, tapering off slightly towards each end, and flanged, as usual, at the bottom. Several had fallen to the ground, of which only a few were broken; and of those which remained entire, two were

bent laterally in a striking and nearly equal degree. The flexure was gradual from end to end. The deviation from a straight line at the ends was 22 in. No cracks were anywhere visible. Many of the cast-iron columns, which remained upright, were curiously twisted at the upper part, as though the metal there had been softened by heat, and yielded without cracking to the superincumbent pressure.

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